

Environmental Consequences of Dredge Spoil Disposal in Long Island Sound, Phase II;
Geophysical Studies, November 1973 - November 1974.

SR -8

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I. INTRODUCTION

Study of the environmental consequences of the use of the New Haven Dump Site for the disposal of dredge spoil began in May 1972. Baseline observations of relevant physical, chemical and biological factors continued until spoil disposal operations started in October of 1973 (see appended list of reports issued). This report deals with the physical processes which result in dispersion of spoil during dredging and dumping, and with subsequent erosion of spoil from the dump site. The objective of the study is two-fold: to monitor the actual dredging and dumping operations so as to determine their effect on the local marine environment and to search for generalizations which will allow the results to be used in assessing other sites and alternate procedures.

During the dredging operation in New Haven Harbor, observations of the amount of material escaping from the dredge into the surrounding water were made. These define the efficiency of the dredge and the siltation in surrounding waters relative to that due to natural causes. The processes by which spoil is transported to the bottom during dumping and the accuracy to which it can be placed at a designated point were determined quantitatively. Bathymetric surveys have been used to define the placement of spoil on completion of dumping and the subsequent changes in size and shape of the spoil pile. Additional information on the internal structure of the spoil pile and the erosion of material from it is obtained from examination of cores. Current meter measurements define the change in the hydraulic flow regime through the dump site due to the presence of the spoil pile. The results show that good accuracy can be attained in spoil placement and that, to within the limits of accuracy of measurement, all of the spoil dumped

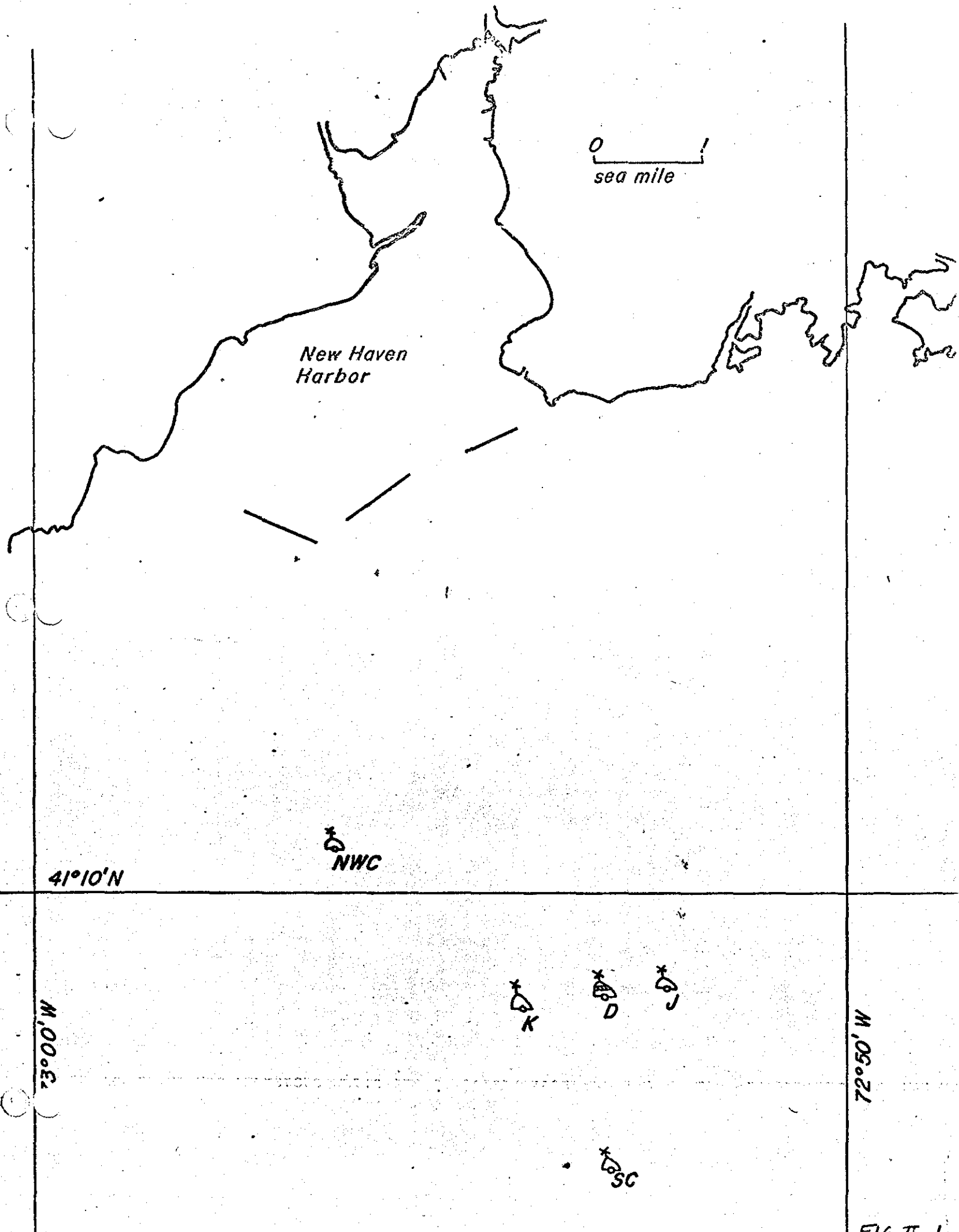
can be accounted for on the dump site. Modification of the point dumping procedure so as to achieve a more uniform distribution of spoil over the dump site and to avoid building the spoil pile high into the water column is recommended for future disposal operations in similar situations.

II. DREDGE AND DUMP OPERATIONS

The location of the New Haven dump site is shown in Fig. II-1. The center of the designated disposal area is marked by buoy "D". The northwest control site, "NWC", and the south control site, "SC", also marked by buoys, were originally established as biological sampling stations. The south control site buoy is used as a calibration point for bathymetric surveys. Buoys "J" and "K" are used for local navigation at the dump site; the track J-D-K is frequently used for bathymetric profiles and the collection of core samples.

During the study period material taken from Guilford Harbor and from several projects in New Haven Harbor was being deposited on the New Haven dump site. The material from New Haven Harbor included spoil from the main channel dredging, from the construction of the Coke Works power station of the United Illuminating Co., and from several ship berths. Records of the source, character, and quantity of material dredged, and of the actual dump locations, were kept by the dredging contractors and Corps of Engineers inspectors.

All of these data are assembled in Table II-1; they show the sequence and rate at which spoil was placed on the dump site. In using this table the limitations of the original data should be kept in mind: The spoil volumes are those estimated by the dredge operators while the classification



NEW HAVEN UMP SCHEDULE

	Dredge #	Dredge Site	Contract	Amount "Mud-Silt" cu yards	Total	Amount mixed mud Sand, clay stones, rocks cu yards	Total	Total Material cu yards
1973								
Oct. 4	cc	Guil. H.	0167	393	393	299	299	692
Oct. 6	cc	Guil. H.	0167	737	1,130	180	479	1,609
Oct. 7	50	New Haven	U.I.	11,175	12,305			12,784
Oct. 8	50	New Haven	U.I.	10,250	22,555			
	cc	Guil. H.	0167	616	23,171	154	633	23,804
Oct. 9	50	New Haven	U.I.	9,650	32,821			
	cc	Guil.	0167	1,074	33,895	189	822	34,717
Oct. 10	50	New Haven	U.I.	11,550	45,445			
	cc	Guil.	0167	647	46,092	114	936	47,028
Oct. 11	50	New Haven	U.I.	6,650	52,742			
	cc	Guil.	0167	737	53,479	39	975	54,454
Oct. 12	50	New Haven	U.I.	12,700	66,179			
	cc	Guil.	0167	841	67,020	45	1,020	68,040
Oct. 13	50	New Haven	U.I.			5,650	6,670	73,690
	cc	Guil.	0167	1,026	68,046	114	6,784	74,830
Oct. 14	50	New Haven	U.I.			5,750	12,534	80,580
Oct. 15	50	New Haven	U.I.			5,600	18,134	
	cc	Guil.	0167	987	69,033	174	18,308	87,341

	Dredge #	Dredge Site	Contract	Amount cu yards "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	total	total material (cu yards)
t. 16	50	New Haven	U.I.			6,450	24,758	93,791
	cc	Guil	0167	553	69,586	98	24,856	94,442
t. 17	50	New Haven	U.I.		69,586	6,000	30,856	100,442
t. 18	50	New Haven	U.I.		69,586	5,100	35,956	105,542
	cc	Guil	0167	762	70,348	88	36,044	106,392
t. 19	50	New Haven	U.I.		70,348	6,600	42,644	112,992
	cc	Guil H.	0167	843	71,191	94	42,738	113,929
t. 20	50	New Haven	U.I.		71,191	5,400	48,138	119,329
	cc	Guil	0167	651	71,842	115	48,253	120,095
t. 21	50	New Haven	U.I.		71,842	3,850	52,103	123,945
t. 22	50	New Haven	U.I.		71,842	2,500	54,603	126,445
t. 23	50	New Haven	N.H.C.		71,842	3,600	58,203	130,045
	cc	Guil	0167	570	72,412		58,203	130,615
t. 24	50	New Haven	N.H.C.		72,412	3,050	61,253	133,665
	cc	Guil H.	0167	814	73,226		61,253	134,479
t. 25	50	New Haven	N.H.C.		73,226	3,600	64,853	138,079
	cc	Guil H.	0167	1,238	74,464		64,853	139,317
t. 26	50	New Haven	N.H.C.		74,464	4,100	68,953	143,417
	50	New Haven	U.I.		74,464	500	69,453	143,917
t. 27	cc	Guil H.	0167	812	75,276	43	69,496	144,772

	Dredge #	Dredge Site	Contract	Amount cu yards "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	total material (cu yards)
Oct. 28								
Oct. 29								
Oct. 30	cc	Guil H.	0167	658	75,934	35	69,531	145,465
Oct. 31	cc	Guil H.	0167	488	76,422		69,531	145,953
Nov. 1	cc	Guil H.	0167	350	76,772		69,531	146,303
Nov. 2								
Nov. 3								
Nov. 4								
Nov. 5	cc	Guil H.	0167	1,711	78,483		69,531	148,014
Nov. 6	cc	Guil H.	0167	904	79,387		69,531	148,918
Nov. 7	cc	Guil H.	0167	537	79,924		69,531	149,455
Nov. 8	cc	Guil H.	0167	376	80,300		69,531	149,831
Nov. 9	cc	Guil H.	0167	904	81,204		69,531	150,735
Nov. 10	cc	Guil H.	0167	816	82,020		69,531	151,551
Nov. 11								
Nov. 12	50	New Haven	N.H.C.		82,020	2,600	72,131	154,151
	cc	Guil H.	0167	1,658	83,678		72,131	155,809
Nov. 13	50	New Haven	N.H.C.		83,678	4,750	76,881	160,559
	cc	Guil H.	0167	941	84,619		76,881	161,500

	Dredge #	Dredge Site	Contract	Amount cu yards "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	Total material (cu yards)
v. 14	50	New Haven	N.H.C.		84,619	4,400	81,281	165,900.
	cc	Guil H.	0167	1,857	86,476		81,281	167,757
v. 15	50	New Haven	N.H.C.		86,476	3,600	84,881	171,357
	cc	Guil H.	0167	1,006	87,482		84,881	172,363
v. 16	50	New Haven	N.H.C.		87,482	2,300	87,181	174,663
v. 17	50	New Haven	N.H.C.		87,482	5,800	92,981	180,463
v. 18	50	New Haven	N.H.C.		87,482	6,900	99,881	187,363
v. 19	50	New Haven	N.H.C.		87,482	3,850	103,731	191,213
	50	New Haven	N.H.C.		87,482	300	104,031	191,513
v. 20	50	New Haven	N.H.C.		87,482	5,250	109,281	196,763
v. 21	50	New Haven	N.H.C.		87,482	9,000	118,281	205,763
v. 22	50	New Haven	N.H.C.		87,482	4,750	123,031	210,513
v. 23	50	New Haven	N.H.C.		87,482	1,900	124,931	212,413
v. 24	50	New Haven	N.H.C.	7,200	94,682		124,931	219,613
v. 25	50	New Haven	N.H.C.	3,930	98,612	2,620	127,551	226,163
v. 26	50	New Haven	N.H.C.	4,000	102,612	3,200	130,751	233,363
v. 27	50	New Haven	N.H.C.	6,300	108,912		130,751	239,663
	52	New Haven	11323 U.I.		108,912	8,300	139,051	247,963
v. 28	50	New Haven	N.H.C.	4,400	113,312	1,100	140,151	253,463
	52	New Haven	U.I.		113,312	5,600	143,751	259,063

	Dred #	Dredge Site	Contract	Amount cu yards "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	Total material yards
n. 8	50	New Haven	N.H.C.	12,450	583,744		251,511	835,255
	52	New Haven	11261		583,744	4,700	256,211	839,955
	cc	Guil. H.	0167	130	583,874	737	256,948	840,822
n. 9	50	New Haven	N.H.C.	11,400	595,274		256,948	852,222
	52	New Haven	11261		595,274	6,100	263,048	858,322
	cc	Guil. H.	0167	309	595,583	721	263,769	859,352
n. 10	50	New Haven	N.H.C.	9,400	604,983		263,769	868,752
	52	New Haven	11261	7,900	612,883		273,769	876,652
n. 11	50	New Haven	N.H.C.	11,750	624,633		263,769	888,402
	52	New Haven	11261	11,100	635,733		263,769	899,502
n. 12	50	New Haven	N.H.C.	11,750	647,483		263,769	911,252
	52	New Haven	11261	11,800	659,283		263,769	923,052
	cc	Guil. H.	0167	656	659,939	73	263,842	923,781
n. 13	50	New Haven	N.H.C.	10,750	670,689		263,842	934,531
	52	New Haven	11261	11,200	681,889		263,842	945,731
n. 14	50	New Haven	N.H.C.	2,000	683,889		263,842	947,731
	52	New Haven	11261	9,750	693,639		263,842	957,481
	cc	Guil. H.	0167	500	694,139	60	263,902	958,041
n. 15	52	New Haven	11261 (610,620)	12,400	706,539		263,902	970,441
n. 16	52	New Haven	11261	14,100	720,639		263,902	984,541
	cc	Guil. H.	0167	468	721,107	52	263,954	985,061

1974

Dredge #	Dredge Site	Contract	Amount cu yards "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	Total material cu yards
an. 1	50	New Haven	N.H.C.	8,950	483,734	227,256	710,990
	52	New Haven	11261	8,200	491,934	227,256	719,190
an. 2	50	New Haven	N.H.C.	4,950	496,884	227,256	724,140
	52	New Haven	11261	496,884	10,900	238,156	735,040
	cc	Guil. H.	0167	325	488	238,644	735,853
an. 3	50	New Haven	N.H.C.	5,000	502,209	238,644	740,853
	52	New Haven	11261	7,725	509,934	238,644	748,578
	cc	Guil. H.	0167	258	386	239,030	749,222
an. 4	50	New Haven	N.H.C.	7,250	517,442	239,030	756,472
	52	New Haven	N.H.C.	9,400	526,842	239,030	765,872
	cc	Guil. H.	0167	302	452	239,482	766,626
an. 5	50	New Haven	N.H.C.	12,700	539,844	239,482	779,326
	52	New Haven	11261	8,250	548,094	239,482	787,576
	cc	Guil. H.	0167	200	579	240,061	788,355
an. 6	50	New Haven	N.H.C.	11,600	559,894	240,061	799,955
	52	New Haven	11261	559,894	6,700	246,761	806,655
an. 7	50	New Haven	N.H.C.	11,250	571,144	246,761	817,905
	52	New Haven	11261	571,144	3,900	250,661	821,805
	cc	Guil. H.	0167	150	850	251,511	822,805

Dredge #	Dredge Site	Contract	Amount cu yards "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	Total material cu yards
	52	New Haven	11261	10,800	439,865	193,179	633,040
	cc	Guil. H.	0167	34	439,899	304	633,382
Dec. 24	50	New Haven	N.H.C.	1,000	440,899	193,483	634,382
	52	New Haven	11261	1,500	442,399	193,483	635,882
Dec. 25							
Dec. 26	50	New Haven	N.H.C.	550	442,999	193,483	636,432
	52	New Haven	11261	2,800	445,749	193,483	639,232
Dec. 27	50	New Haven	N.H.C.	6,900	452,649	193,483	646,132
	52	New Haven	11261	350	452,999	4,550	651,032
Dec. 28	50	New Haven	N.H.C.	9,500	462,499	198,033	660,532
	52	New Haven	11261		462,499	6,350	666,882
	cc	Guil. H.	0167	32	462,531	610	667,524
Dec. 29	50	New Haven	N.H.C.	4,000	466,531	204,993	671,524
	52	New Haven	11261		466,531	6,450	677,974
	cc	Guil. H.	0167	23	466,554	443	678,440
Dec. 30	50	New Haven	N.H.C.		466,554	5,600	684,040
	52	New Haven	11261		466,554	5,500	689,540
	cc	Guil. H.	0167	30	466,584	570	690,140
Dec. 31	50	New Haven	N.H.C.	7,200	473,784	223,556	697,340
	52	New Haven	11261	1,000	474,784	3,700	702,040

	Dredge #	Dredge Site	Contract	Amount cu yards "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	Total material cu yards
Dec. 15	50	New Haven	N.H.C.	13,500	321,196		187,095	508,291
	52	New Haven	11261	10,150	331,346		187,095	518,441
	cc	Guil. H.	0167	133	331,479	200	187,295	518,774
Dec. 16	50	New Haven	N.H.C.	10,100	341,579		187,295	528,874
	52	New Haven	11261	9,350	350,929		187,295	538,224
Dec. 17	50	New Haven	N.H.C.	4,450	355,379		187,295	542,674
	52	New Haven	11261		355,379	3,000	190,295	545,674
Dec. 18	50	New Haven	N.H.C.	9,000	364,379		190,295	554,674
	52	New Haven	11261	8,250	372,629		190,295	562,924
Dec. 19	50	New Haven	N.H.C.	3,700	376,329		190,295	566,624
	52	New Haven	11261	11,000	387,329		190,295	577,624
Dec. 20	50	New Haven	N.H.C.	6,150	393,479		190,295	583,774
	52	New Haven	11261	4,700	398,179	2,000	192,295	590,474
	cc	Guil. H.	0167	220	398,399	512	192,807	591,206
Dec. 21	50	New Haven	N.H.C.	7,600	405,999		192,807	598,806
	52	New Haven	11261	4,250	410,249		192,807	603,056
Dec. 22	50	New Haven	N.H.C.	7,100	417,349		192,807	610,156
	52	New Haven	11261	3,000	420,349		192,807	613,156
	cc	Guil. H.	0167	66	420,415	372	193,179	613,594
Dec. 23	50	New Haven	N.H.C.	8,650	429,065		193,179	622,244

	Ledge #	Dredge Site	Contract	Amount cu yard "Mud Stick"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	total material cu yards
Dec. 8	50	New Haven	N.H.C.	3,750	210,493		173,606	384,099
	52	New Haven	N.H.C.	5,500	215,993		173,606	389,599
	cc	Guil. H.	0167	1,226	217,219		173,606	390,825
Dec. 9	50	New Haven	N.H.C.	4,350	221,569		173,606	395,175
	52	New Haven	N.H.C.	3,650	225,219		173,606	398,825
Dec. 10	50	New Haven	N.H.C.	11,150	236,369		173,606	409,975
	52	New Haven	N.H.C. (11261)	9,500	245,869		173,606	419,475
	cc	Guil. H.	0167	1,324	247,193		173,606	420,799
Dec. 11	50	New Haven	N.H.C.	8,300	255,493		173,606	429,099
	52	New Haven	11261	9,700	265,193		173,606	438,799
	cc	Guil. H.	0167	715	265,908		173,606	439,514
Dec. 12	50	New Haven	N.H.C.	10,900	276,808		173,606	450,414
	52	New Haven	11261		276,808	8,250	181,856	458,664
	cc	Guil. H.	0167	696	277,504	78	181,934	459,438
Dec. 13	50	New Haven	N.H.C.	6,900	284,404		181,934	466,338
	52	New Haven	11261		284,404	4,300	186,234	470,638
	cc	Guil. H.	0167	685	285,089	456	186,690	471,779
Dec. 14	50	New Haven	N.H.C.	12,000	297,089		186,690	483,779
	52	New Haven	11261	10,000	307,089		186,690	493,779
	cc	Guil. H.	0167	607	307,696	405	187,095	494,791

	Dredge #	Dredge Site	Contract	Amount cu yard "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	al material cu yards
Nov. 29	50	New Haven	N.H.C.	2,450	115,762	1,005	146,756	262,518
	52	New Haven	UI 11323		115,762	6,400	153,156	268,918
Nov. 30	50	New Haven	N.H.C.	5,950	121,712		153,156	274,868
	52	New Haven	U.I.	5,300	127,012		153,156	280,168
Dec. 1	50	New Haven	N.H.C.	10,100	137,112		153,156	290,268
	52	New Haven	U.I.		137,112	3,800	156,956	294,068
Dec. 2	50	New Haven	N.H.C.	8,400	145,512		156,956	302,468
	52	New Haven	U.I.		145,512	4,050	161,006	306,518
Dec. 3	50	New Haven	N.H.C.	8,600	154,112		161,006	315,118
	52	New Haven	U.I.	600	154,712	2,200	163,206	317,918
Dec. 4	50	New Haven	N.H.C.	8,050	162,762		163,206	325,968
	52	New Haven	N.H.C.	3,800	166,562	2,600	165,806	332,368
Dec. 5	50	New Haven	N.H.C.	7,000	173,562		165,806	339,368
	52	New Haven	N.H.C.	5,900	179,462		165,806	345,268
Dec. 6	50	New Haven	N.H.C.	6,750	186,212		165,806	352,018
	52	New Haven	N.H.C.	8,550	194,762		165,806	360,568
	cc	Guil. H.	0167	981	195,743		165,806	361,549
Dec. 7	50	New Haven	N.H.C.	11,000	206,743		165,806	372,549
	52	New Haven	N.H.C.		206,743	7,800	173,606	380,349

	Dredge #	Dredge Site	Contract	Amount cu yard "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	Total material cu yards
Jan. 17	50	New Haven	N.H.C.	4,150	725,257		263,054	989,211
	52	New Haven	11261	9,650	734,907		263,054	997,961
	cc	Guil. H.	0167	608	735,358	68	264,022	999,380
Jan. 18	50	New Haven	N.H.C.	4,100	739,615		264,022	1,003,637
	52	New Haven	11261	12,900	752,515		264,022	1,016,537
	cc	Guil. H.	0167	597	753,112	66	264,088	1,017,200
Jan. 19	50	New Haven	N.H.C.	7,500	760,612		264,088	1,024,700
	52	New Haven	11261	11,900	772,512		264,088	1,036,600
Jan. 20	50	New Haven	N.H.C.	5,500	778,012		264,088	1,042,100
	52	New Haven	11261	14,200	792,212		264,088	1,056,300
Jan. 21	50	New Haven	N.H.C.	6,300	798,512		264,088	1,062,600
	52	New Haven	11261	6,000	804,512	3,850	267,938	1,072,450
Jan. 22	50	New Haven	N.H.C.	10,250	814,762		267,938	1,082,700
	52	New Haven	11261	3,450	818,212	3,800	271,738	1,089,950
	cc	Guil. H.	0167	270	818,482	30	271,768	1,090,250
Jan. 23	50	New Haven	N.H.C.	8,920	827,402		271,768	1,099,170
	52	New Haven	11261		827,402	6,000	277,768	1,105,170
	cc	Guil. H.	0167	560	827,962	62	277,830	1,105,792
Jan. 24	50	New Haven	N.H.C.	8,000	835,962		277,830	1,113,692
	52	New Haven	11261		835,962	6,100	283,930	1,119,892
	cc	Guil. H.	0167	816	836,778	91	284,021	1,120,799

Dredge #	Dredge Site	Contract	Amount cu yards "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	Total material cu yards
an. 25	50	New Haven	N.H.C.	6,900	843,678		1,127,699
	52	New Haven	11261		843,678	5,700	1,133,399
	cc	Guil. H.	0167	1,003	844,681	112	1,134,514
an. 26	50	New Haven	N.H.C.	6,900	851,581		1,141,414
	52	New Haven	11261		851,581	7,400	1,148,814
	cc	Guil. H.	0167	1,045	852,626	116	1,149,975
an. 27	50	New Haven	N.H.C.	5,300	857,926		1,155,275
	52	New Haven	11261	5,700	863,626		1,160,975
an. 28	50	New Haven	N.H.C.	11,900	875,526		1,172,875
	52	New Haven	11261	6,000	881,526	6,000	1,184,875
	cc	Guil. H.	0167	1,023	882,549	114	1,186,012
an. 29	cc	Guil. H.	0167	165	882,714	110	1,186,287
	52	New Haven	261		882,714	7,500	1,193,787
	50	New Haven (US Gov.)	11261 (US Gov.)	6,500	889,214		1,200,287
an. 30	50	New Haven	N.H.C.	13,400	902,614		1,213,689
	52	New Haven	11261	10,000	912,614	750	1,224,437
	cc	Guil. H.	0167	940	913,554	626	1,226,003
an. 31	cc	Guil. H.	0167	1,102	914,656	122	1,227,227
	52	New Haven	061		914,656	3,500	1,230,727
	50	New Haven	USG-11261	3,600	918,256		1,234,327

	Dredge #	Dredge Site	Contract	Amount cu yards "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	Total material cu yards
Mar. 9	52	N.H. Terminal	11380	5,305	1,138,497	1,900	367,727	1,506,224
Mar. 10	52	New Haven	11261	1,000	1,139,497		367,727	1,507,224
	52	N.H. Terminal	11380		1,139,497	500	368,227	1,507,724
Mar. 11	52	U.I. - N.H.	11323	3,900	1,143,397		368,227	1,511,624
	52	New Haven	11261	2,900	1,146,297		368,227	1,514,524
Mar. 12	52	Wyatt Oil-NH	11378	11,876	1,158,173		368,227	1,526,400
	52	U.I. - N.H.	11323	200	1,158,373		368,227	1,526,600
Mar. 13	52	New Haven	11261	2,900	1,161,273		368,227	1,529,500
	52	Wyatt Oil-NH	11378	900	1,162,173		368,227	1,530,400
Mar. 14	52	Wyatt Oil-NH	11378	2,200	1,164,373		368,227	1,532,600
	52	New Haven	11261	1,100	1,165,473		368,227	1,533,700
Mar. 15	52	New Haven	11261	1,600	1,167,073		368,227	1,535,300

	Dredge #	Dredge Site	Contract	Amount cu yards "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	Total material (cu yards)
Feb. 13	52	New Haven	11261	10,050	1,051,259	.	320,217	1,371,476
Feb. 14	52	New Haven	11261	2,327	1,053,586	4,323	324,540	1,378,126
Feb. 15	52	New Haven	11261	2,000	1,055,586	6,500	331,040	1,386,626
Feb. 16	52	New Haven	11261		1,055,586	9,600	340,640	1,396,226
Feb. 17	52	New Haven	11261	11,800	1,067,386		340,640	1,408,026
Feb. 18	52	New Haven	11261	4,500	1,071,886	4,600	345,240	1,417,126
Feb. 19	52	New Haven	11261	2,600	1,074,486	4,000	349,240	1,423,726
Feb. 20-25	52	New Haven	11261					
Feb. 26	52	New Haven	11261		1,074,486	8,500	357,740	1,432,226
Feb. 27	52	New Haven	11261	6,000	1,080,486	3,600	361,340	1,441,182
Feb. 28	52	New Haven	11261	8,000	1,088,486		361,340	1,449,826
Mar. 1	52	New Haven	11261	10,450	1,098,936		361,340	1,460,276
Mar. 2								
Mar. 3								
Mar. 4	52	New Haven	11261	7,200	1,106,136		361,340	1,467,476
Mar. 5	52	New Haven	11261	1,400	1,107,536		361,340	1,468,876
	52	N.H. Terminal	11380		1,107,536	4,487	365,827	1,473,363
Mar. 6	52	N.H. Terminal	11380	6,351	1,113,887		365,827	1,479,714
Mar. 7	52	N.H. Terminal	11380	8,403	1,122,290		365,827	1,488,117
Mar. 8	52	N.H. Terminal	11380	10,902	1,133,192		365,827	1,499,019

	Dredge #	Dredge Site	Contract	Amount cu yards "Mud Silt"	Total	cu yards mixed mud Sand, clay stones, rocks	Total	Total material cu yards
Feb. 1	52	New Haven	USG-11261	8,800	927,056		316,071	1,243,127
	50	New Haven	USG-11261	10,300	937,356		316,071	1,253,427
	cc	Guil. H.	0167	370	937,726	41	316,112	1,253,838
Feb. 2	52	New Haven	USG-11261	7,800	945,526		316,112	1,261,638
	50	New Haven	USG-11261	10,800	956,326		316,112	1,272,438
	cc	Guil. H.	0167	336	956,662	37	316,149	1,272,811
Feb. 3	52	New Haven	USG-11261	6,600	963,262		316,149	1,279,411
	50	New Haven	USG-11261	5,800	969,062		316,149	1,285,211
Feb. 4	52	New Haven	USG-11261	7,350	976,412		316,149	1,292,561
	50	New Haven	USG-11261	5,600	982,012		316,149	1,298,161
	cc	Guil. H.	0167	1,197	983,209	68	316,217	1,299,426
Feb. 5	52	New Haven	USG-11261	8,350	991,559		316,217	1,307,776
	50	New Haven	USG-11261	3,600	995,159		316,217	1,311,376
Feb. 6	52	New Haven	USG-11261	10,550	1,005,709		316,217	1,321,926
Feb. 7								
Feb. 8	52	New Haven	11261	6,000	1,011,709	2,800	319,017	1,330,726
Feb. 9								
Feb. 10	52	New Haven	11261	12,000	1,023,709	1,200	320,217	1,343,926
Feb. 11	52	New Haven	11261	8,550	1,032,259		320,217	1,352,476
Feb. 12	52	New Haven	11261	8,950	1,041,209		320,217	1,361,426

into "mud-silt" and "sand, clay, stone" is based, at least in part, on the ease or difficulty of excavating the material with a bucket dredge as well as its appearance.

All spoil was "point dumped" at the buoy marking the New Haven disposal site. This is at

41° 08!9 N

72° 53!1 W

During periods of calm weather the scows were discharged alongside the buoy; in poor weather a clearance of up to about 200 yards from the buoy was allowed.

Properties of Dredge Spoil. The properties of the freshly dredged spoil as deposited in scows ready for transportation to the dump site were measured on cores taken from a loaded scow. The spoil was silt-clay from the New Haven ship channel. The water content of a series of sections cut from one of the cores was measured with the results shown in Table II-2.

Table II-2

Water Content of Fresh Dredge Spoil

<u>Sample</u>	<u>Sample Thickness</u>	<u>% Water</u>
1 (Top)	5.3 cm	71.9
2	5.1	71.8
3	4.7	72.6
4	5.0	72.9
5	5.0	71.1
6	4.6	71.2
7	4.9	74.6
8	5.0	75.1
9	4.5	71.0

Average water content = 72.5

Cores taken from the channel bottom in the area where the dredge was working have a water content between 42 and 45%; bucket dredging therefore increases the water content of the sediment by about 30%.

The strength properties of the fresh spoil were measured by unconfined compression tests on cylindrical sections cut from the cores. The measurements were made with an Instron testing machine fitted with a compression load cell; yield stress was computed from the observed load at yield and the inside diameter of the core tubes. The results are shown in Table II-3. The

Table II-3

<u>Depth to top of section cut</u>	<u>Height of section cut</u>	<u>Sample height</u>	<u>Yield stress</u>	<u>Strain at yield</u>
13.0 cm	8.9 cm	7.6 cm	5.8 mbar	0.167
21.9	7.6	6.7	6.9	0.180
29.5	6.0	5.1	7.4	0.150
35.5	5.1	3.1	17.4	0.173
48.2	6.3	5.1	9.9	0.238

compressive strength of the spoil is comparable to, but somewhat lower than, the compressive strength of cores taken from the silt-clay bottom of central Long Island Sound.

III. TURBIDITY AND SILTATION CAUSED BY DREDGING IN NEW HAVEN HARBOR

Dredge operations create turbidity in the surrounding water by agitation of the bottom and by loss of sediment from the dredge machinery. Undesired siltation and a degradation of water quality may result. Measurements of the amount of turbidity and siltation created by a dredge working on the mud bottom of New Haven Harbor are reported here.

Methods. The turbidity in waters surrounding an operating dredge can be measured directly by any of several standard methods, but the resultant siltation cannot be so easily found. The most direct way of determining the siltation resulting from dredge operation would be to collect samples of the sediment arriving from the dredge site at the stations of interest, as by the use of sediment traps. However, this method is impractical in areas where waves and tidal streams generate natural turbidity by resuspension of the bottom sediments because there is usually no way of distinguishing, in the total amount of silt settling in the trap, that fraction which originates at the dredge. Since an operating dredge is effectively a continuous, fixed point source of turbidity, siltation rates are better determined by measurements of the net flow of suspended sediment across a series of sections through the water column surrounding the dredge. One method of accomplishing this is to measure the suspended sediment concentration as a function of depth along, and the net flow of water across, each section. This method may be used when the transport of suspended solids by advection is large compared to the transport by diffusion. This is a practical situation frequently encountered.

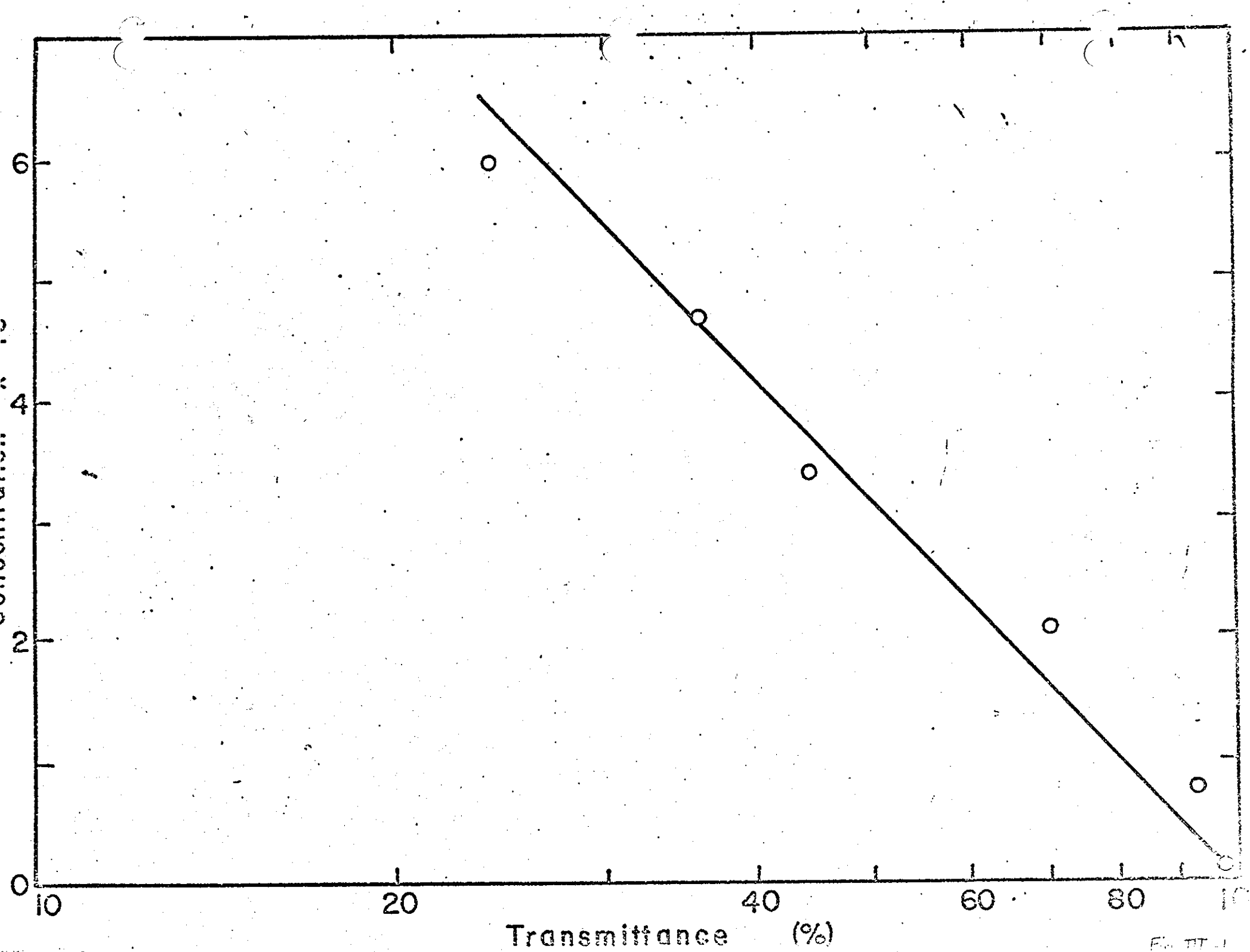
Silt concentrations can be measured by filtering water samples, but the amount of data that can be obtained by this method is usually inadequate to define the flux of suspended solids. Indirect methods are more appropriate. In the present study concentrations of suspended solids are measured by the optical transmittance method using a 10 cm path length white light transmissometer. Transmittance is continuously recorded as the instrument is towed along each section at successively greater depths. To find the concentration of suspended solids from the measured transmittance, it is necessary first

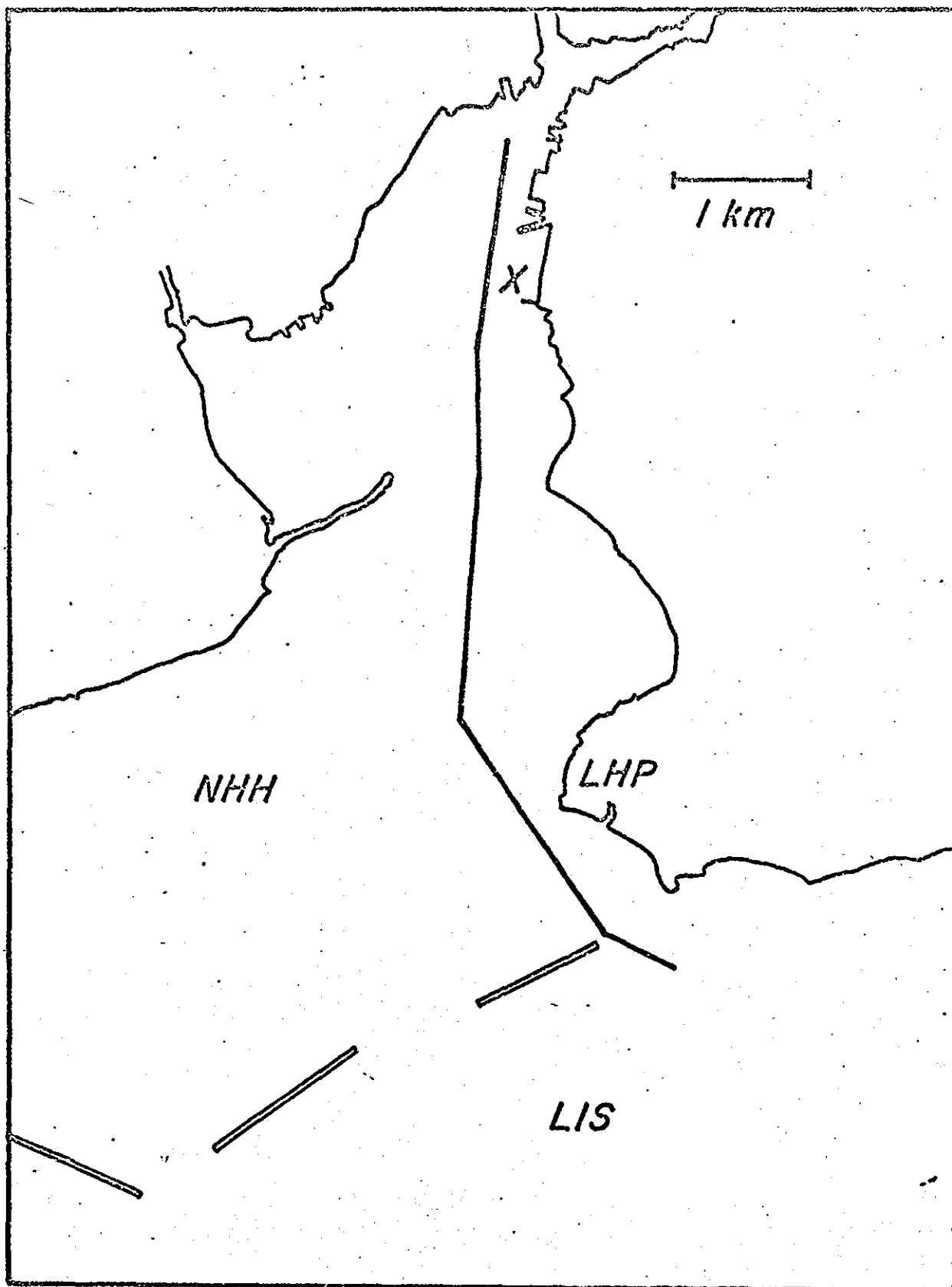
to correct for turbidity due to other constituents, such as substances in solution and plankton, and to have a calibration between suspended solids and transmittance.

When a dredge is operating in a fixed position with a tidal stream flowing past it, the background turbidity can be determined from measurements made upstream of the dredge once a pre-dredge survey showing the distribution of suspended sediments within the study area has been completed. All observed turbidity above background levels can then be traced to the dredge; this will be called the "excess" turbidity. The calibration of the transmissometer is made by resuspending in sea water weighed quantities of sediment collected from the bottom in the study area. The resultant calibration curve is shown in Fig. III-1.

Observations. Data were obtained in the vicinity of a dredge operating at the edge of the ship channel in New Haven Harbor. Figure III-2 shows the location of the study area. The bottom of the harbor consists of silty sand of high water content except in the upper end of the inner harbor where there are accumulations of various waste materials. Analysis of sediment collected from the dredge site shows a water content of 42%; the solids are 35% sand, 40% silt, and 25% clay.

In order to define the natural turbidity conditions in the study area, a series of optical transmittance measurements were made in the harbor and surrounding waters during the year before the initiation of dredging. The procedure used is to tow the transmissometer at a depth of one meter while making a continuous record of transmittance. Profiles of turbidity vs. depth are recorded at a number of stations. The track followed in the turbidity tows through New Haven Harbor (NHH) is shown in Fig. III-2. (In

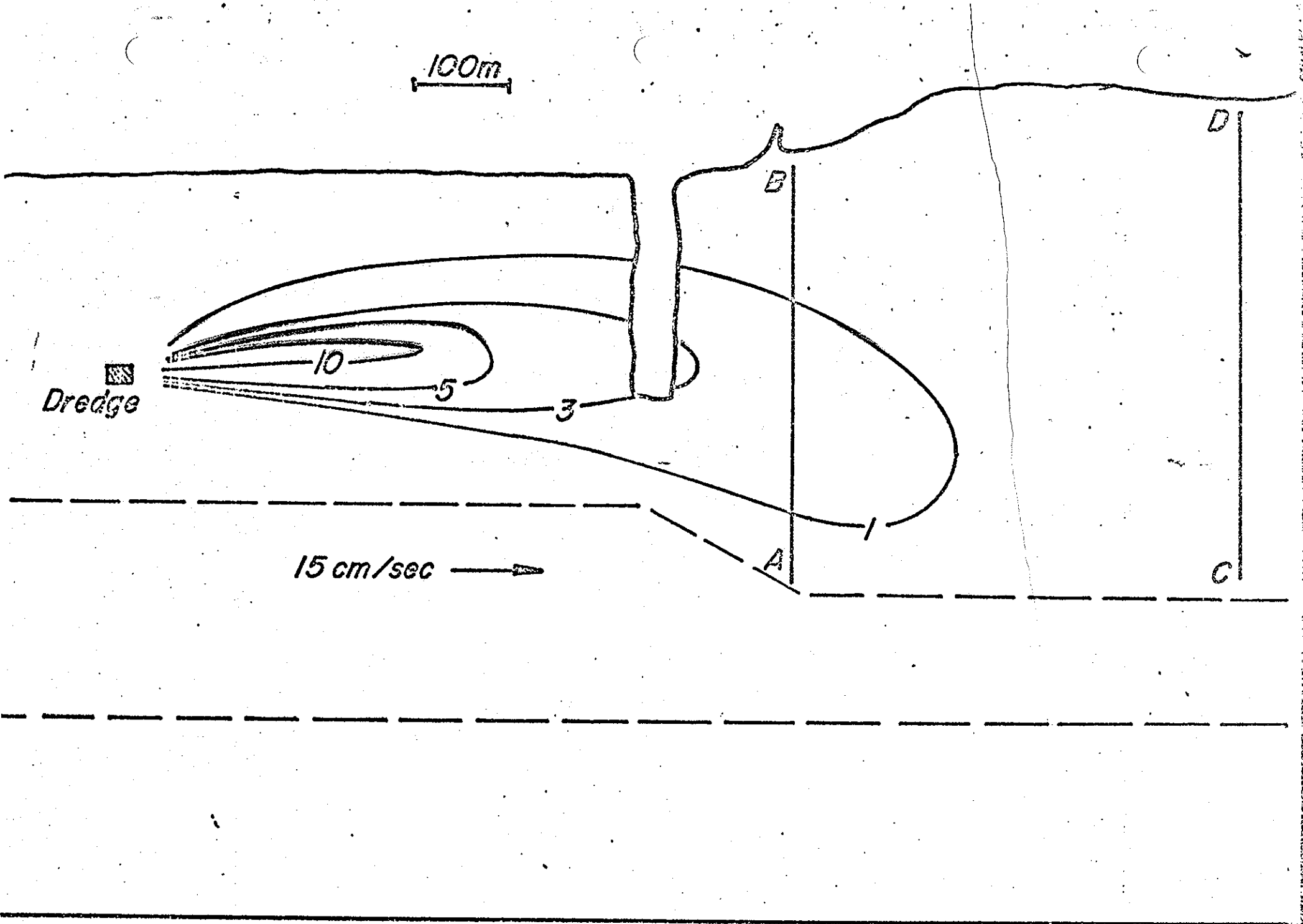




this figure X is the dredge site, LHP is Lighthouse Point and LIS is Long Island Sound.) There is essentially no variation of turbidity with depth along this track so that a single tow suffices. Tows were made on 11 days over the course of the year. Turbidity is found to be essentially uniform along the track on each occasion except at the head of the harbor, where it is raised by industrial waste effluents, and seaward of Lighthouse Point, where it is strongly influenced by sea state. Within the harbor the transmittance is usually between 70 and 95% (for a 10 cm path length) and does not show a simple relation to either wind or sea conditions. This is the background turbidity for subsequent observations during the dredge period; because of its variability it must be determined before each measurement of excess turbidity.

A clamshell dredge fitted with a 14 cubic yard mud bucket began operations in October of 1973. At the normal rate of operation one bucket of spoil is lifted each 1.5 min. and deposited in a 2000 cubic yard capacity scow alongside. Turbidity tows were made over 6 sections near the dredge over a period of 1.5 hr. during which time a steady ebb current was flowing. The upstream background transmittance was 90% while these measurements were being made; excess turbidity is easily detected against this background, the transmittance near the dredge being as low as 5%. Turbidity was uniform with depth in most of the study area. Concentrations of suspended solids due to dredging are calculated from the observed excess turbidities and the calibration curve in Fig. III-1.

The turbidity pattern around the dredge is shown by curves of constant concentration of suspended solids in Fig. III-3. The contours are identified by weight fraction in units of 10^{-4} . A plume of turbid



water flows away from the dredge with the ebb current. The westward edge of the plume is sharply defined and no excess turbidity reaches as far west as the ship channel.

Discussion. The flux of solid particles crossing a unit area of any vertical section is obtained from the measured concentration of solids and the water velocity. Velocities in the study area are well known from earlier surveys (summarized by Duxbury, 1963) and were not measured directly. The total flow over any section is then found by integrating the flux. Transport by diffusion, as distinct from advection, is negligible, as can be shown by order of magnitude estimates assuming diffusion coefficients in the range of 10^3 to $10^4 \text{ cm}^2/\text{sec}$. The flux of solids can also be expressed in terms of the volume equivalent of settled solids of density 1.5 gm/cm^3 . In these terms the total flow of solids over the section closest to the dredge is $0.25 \text{ m}^3/\text{min}$. Since the dredge is lifting material at the rate of $10 \text{ m}^3/\text{min}$, its loss rate is 2.5% of the solids dug and transferred to the receiving scow. This efficiency is typical of that obtained with modern bucket dredge equipment.

Where the solids lost from the dredge are finally deposited can be determined from the flux over the other sections. The flow of silt past section AB (Fig. 3) is $0.1 \text{ m}^3/\text{min}$ or about 40% of the material released. The flow over CD is $0.05 \text{ m}^3/\text{min}$. Thus, siltation is occurring over the area downstream of the dredge. The average accumulation rate between sections AB and CD is about 0.25 mm/day (allowing for the fact that the ebb current flows for only half of the day). In a project where 10^5 m^3 of silt is dredge from the work site, nearly half a centimeter of silt will accumulate in this area. The significance of this accumulation may be judged by

comparison with the siltation of the bottom due to natural causes. The rate of accumulation of sediment in area ABCD due to new material being brought into the harbor by natural causes is minute compared to the siltation caused by the dredge. However, shallow water such as this is subject to wave action during storms. A typical winter storm is observed to reduce the transmittance of the water over a mud bottom to about 6%, corresponding to a silt concentration of 12×10^{-4} parts by weight. When this silt settles out of the water column, it will deposit a layer about 1.7 mm thick. The total silt deposit expected from the dredging operation is, therefore, equivalent to that deposited by four winter storms. Since 10 or more such storms occur in a typical season, the dredging is not a significant perturbation on the natural environment of the harbor.

IV. DISPERSION OF DREDGE SPOIL DURING DUMPING*

Introduction. A problem encountered in the disposal of dredged material at sea is the accuracy to which the spoil can be placed on a designated dump site. It is anticipated that currents, particularly tidal streams, may disperse spoil containing appreciable amounts of silt or clay over considerable distances during the time required for transit from the surface to the bottom. (Subsequent erosion of spoil which reaches the bottom may also occur, but is not considered here.) A series of turbidity measurements has been made at the New Haven spoil ground in Long Island Sound ($41^{\circ}08'.9$ N, $72^{\circ}53'.18$ W) during the dumping of material dredged from New Haven and Guilford Harbors in order to define the processes by which spoil is trans-

* This section will be published in Estuarine and Coastal Marine Science, Vol. 2.

ported to the bottom. These dumping operations are among the first to be carried out with precise navigational control, thereby permitting quantitative observations of the disposition of the spoil. The material being dumped is marine silt of high water content, presumably material highly susceptible to dispersion. The water depth at the dump site is 20 meters and the tidal stream is rotary, so that the current is never less than about 6 cm/sec. Maximum current speeds 2 m above the bottom range from 30 cm/sec (springs) to 16 cm/sec (neaps). Spoil is hauled to the dump site in scows of 1200 (Guilford) and 2000 (New Haven) m^3 capacity; these are held dead in the water at a station buoy and discharged by opening bottom doors. The method of observation used is to measure the water velocity and the concentration of contained solids at various positions around the dump site during and after discharge of a scow and to calculate from these data the resultant flux of suspended sediment.

Methods. The character of the tidal stream at the dump site has been determined from records of the current made over a period of 18 months. During most of this time water speed and direction have been recorded with a meter set on a taut mooring at an elevation, z , of 2 m above the bottom. Additional data for shorter periods of time have been obtained from a 3-meter array measuring at the bottom, at mid-depth, and near the surface, and from the tracking of drifters. Analysis of the results in terms of a tidal stream and a non-tidal circulation is presented elsewhere (Gordon and Pilbeam, 1975). The dominant flow is in the east-west direction; there is a smaller, out-of-phase north-south component. Superimposed on the rotary tidal stream is a well-defined, non-tidal flow. At $z = 2$ m the average annual net flow

is 1.6 cm/sec westwards. This varies only slowly through the year, being greatest in early summer and least in late autumn. Salinity measurements show the presence of a distinct layer of relatively fresh surface water over a more saline bottom water throughout most of the year. The boundary between the layers is at about mid-depth. The surface water flows eastwards. The total tidal velocity at any time can be calculated with the aid of the harmonic constants of the tidal stream, which have been computed from the current meter data. However, turbulent velocity fluctuations in the tidal stream are large (velocities up to 80 cm/sec are occasionally observed). Hence one recording current meter is always kept in operation near the spoil ground during the dump operations studied.

The concentration of solid material in the water at any point is determined by measurement of optical transmittance with a 10 cm path length white light transmissometer. The instrument used is fitted with a pressure sensor so that a continuous record of transmittance versus depth can be made. The transmissometer is calibrated by immersion in water containing known weight fractions of silt collected in the study area. More accurate methods of measuring suspended sediment concentrations are available, but only the transmittance method permits observations to be made with the rapidity required in this study.

The tidal stream resuspends the silty mud found on the bottom at the dump site, creating a background turbidity which is always present. Periodic observations of the amount and distribution of suspended sediment have been made for a period of over one year. The concentration of sediment is found to decrease upwards from the bottom; integration of the concentration profile gives the total amount of sediment in the water column. This is

found to vary, generally from 10 to 50 mgm/cm^2 , with the maximum ever observed being 100 mgm/cm^2 . The amount of suspended material is usually greatest at the time of spring tides and least at neaps. The change over any one tidal cycle is small. Hence, a single turbidity profile taken before the start of a given dumping operation suffices to determine the background concentration of sediments at each depth in the water column.

Three different observational procedures have been used to determine the distribution of excess turbidity due to spoil discharge, as follows:

1. The observing boat is anchored downstream of the scow and the transmissometer held a fixed distance above the bottom. A continuous record of transmittance is made before, during, and after the time when the scow is discharged.

2. The observing boat is anchored, usually downstream of the scow, and repeated turbidity profiles through the water column from surface to bottom are recorded beginning at the time of spoil discharge.

3. Immediately the scow is discharged and moved away; a marker buoy is placed at the exact dump site. A second buoy attached to a drogue set for a depth of 10 meters (called the "drifter") is simultaneously released. Repeated turbidity profiles are then recorded alternately at the dump site and at (or near) the drifter.

In all cases, observations are continued until the turbidity returns to its background level. The motion of the drifter, when in use, is tracked by fixes taken on navigational control buoys and on shoreside landmarks. The trajectory of water passing the dump site is calculated from the current meter and drifter records.

Observations. Turbidity observations have been made during seven different spoil disposal operations at the New Haven site, as summarized in Table IV-1. Additional observations were made on the first day over a wide area surrounding the drop site to make sure that no turbidity other than that revealed by the standard schedule of observations escapes from the spoil area. The volume of spoil discharged from the scow is determined in each case from the records kept by the dredge operator. Spoil composition is determined from available analyses of cores previously collected in the areas dredged.

Typical of the results obtained by recording repeated turbidity profiles at the drop site are the curves in Fig. IV-1. The curves are identified in terms of minutes before or after the time of spoil discharge, D. Two minutes is required for the scow to be towed away and for the measuring boat to move into its place and begin observations. Profiles are made once each minute; only representative curves are shown in the figure. The concentration of suspended solids is expressed as weight fraction and the height, z , above the bottom is in meters. Water depth at the time of discharge is 10 meters. During the time that these measurements were made the recorded tidal current at $z = 2$ m was weak; at D+26 min. water which was at the drop site at time D had been displaced by 20 meters. The curves show that there is essentially no turbidity in the water column above a height of 5 meters. A cloud of highly turbid water initially about 4 meters thick is present on the bottom at the drop site. This turbid cloud settles out over a period of 26 min. At times after D+26 min. only the background turbidity, essentially the same as that observed before the drop, remains at this site.

Table IV-1

Summary of Observations at Spoil Drops

<u>Day/Month/Year</u>	<u>Drop Time*</u>	<u>Method of Observation</u>	<u>Volume Discharged</u>	<u>Source</u>	<u>Spoil Composition</u>
08/10/73	1325Q	3	1850 m ³	N.H.	42% water 35% sand, 40% silt, 25% clay
09/10/73	1535Q	3	1850	N.H.	42% water 20% sand, 60% silt, 20% clay
10/10/73	1314Q	3	1850	N.H.	42% water 20% sand, 60% silt, 20% clay
24/10/73	1551Q	1	900	G	56% water 10% sand, 90% silt and clay
25/10/73	1608Q	2	900	G	56% water 10% sand, 90% silt and clay
05/11/73	1250R	2	1200	G	56% water 10% sand, 90% silt and clay
30/01/74	1600Q	1	2300	N.H.	66% water 15% sand, 60% silt, 25% clay

Methods:

1. Continuous turbidity record, fixed height and location
2. Repeat turbidity profiles, fixed location
3. Repeat turbidity profiles at drop site and drifter

* Local time: Q = GMT - 4^h, R = GMT - 5^h

091073
Drop Site

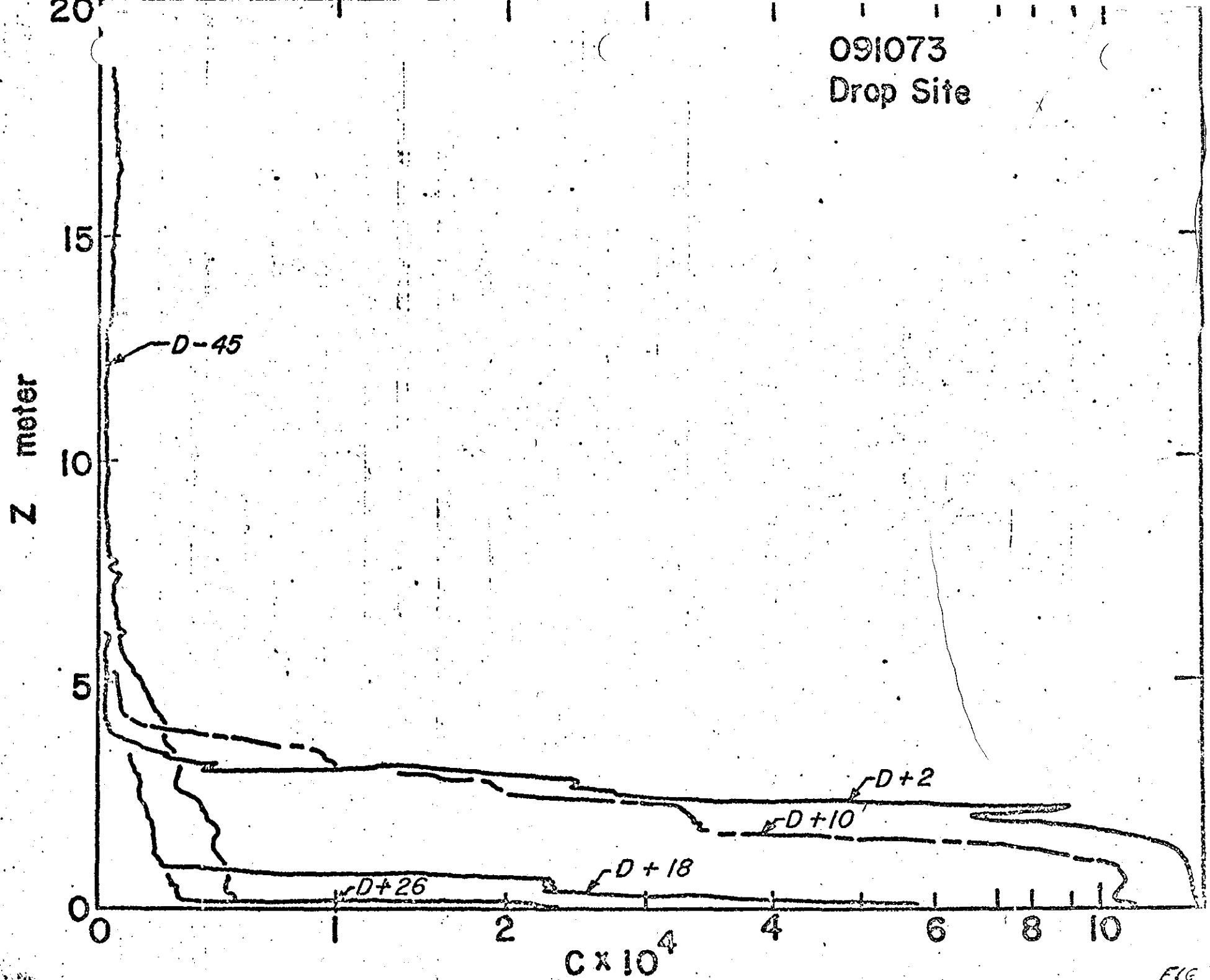


FIG. IV-1

Turbidity profiles at a drifter released at the place where the scow was discharged were made alternately with those at the drop site. The drifter traveled away from the drop site at an average speed of 5.5 m/min. in direction 109 (true). This set of observations was made near the time of minimum current at $z = 2$ m; the surface current runs substantially faster than the bottom current at this stage of the tide. The drifter profiles reveal the presence of the bottom turbid layer at times D+6 and D+14, showing that this cloud has spread at least to a distance of 77 meters from the drop site in 14 min. There is a corresponding decrease in thickness of the bottom cloud.

There is also present at the drifter site a turbid cloud in the upper part of the water column which is distinct from the bottom turbid layer. Sediment concentrations in the upper cloud are less than those near the bottom. No evidence of the upper turbid cloud is observed in the profiles at the drop site. The distance between the drop site and the drifter, therefore, places a limit on the size of the upper cloud; for the observed curves to be consistent the upper cloud must be less than 30 meters in radius at 6 min. after the completion of spoil discharge. The drifter data also place a bound on the size of the bottom turbid layer: this layer is not observed at the drifter after D+14 min.; the data in Fig. IV-1 indicate that the bottom cloud has not reached zero thickness in this time. It follows that the bottom cloud does not extend much beyond 100 meters from the drop site.

An alternate way of taking turbidity profiles is from a fixed station downstream of the dump site. Fig. IV-2 shows representative data taken this way. The observing boat was 50 meters from the scow at the time spoil was

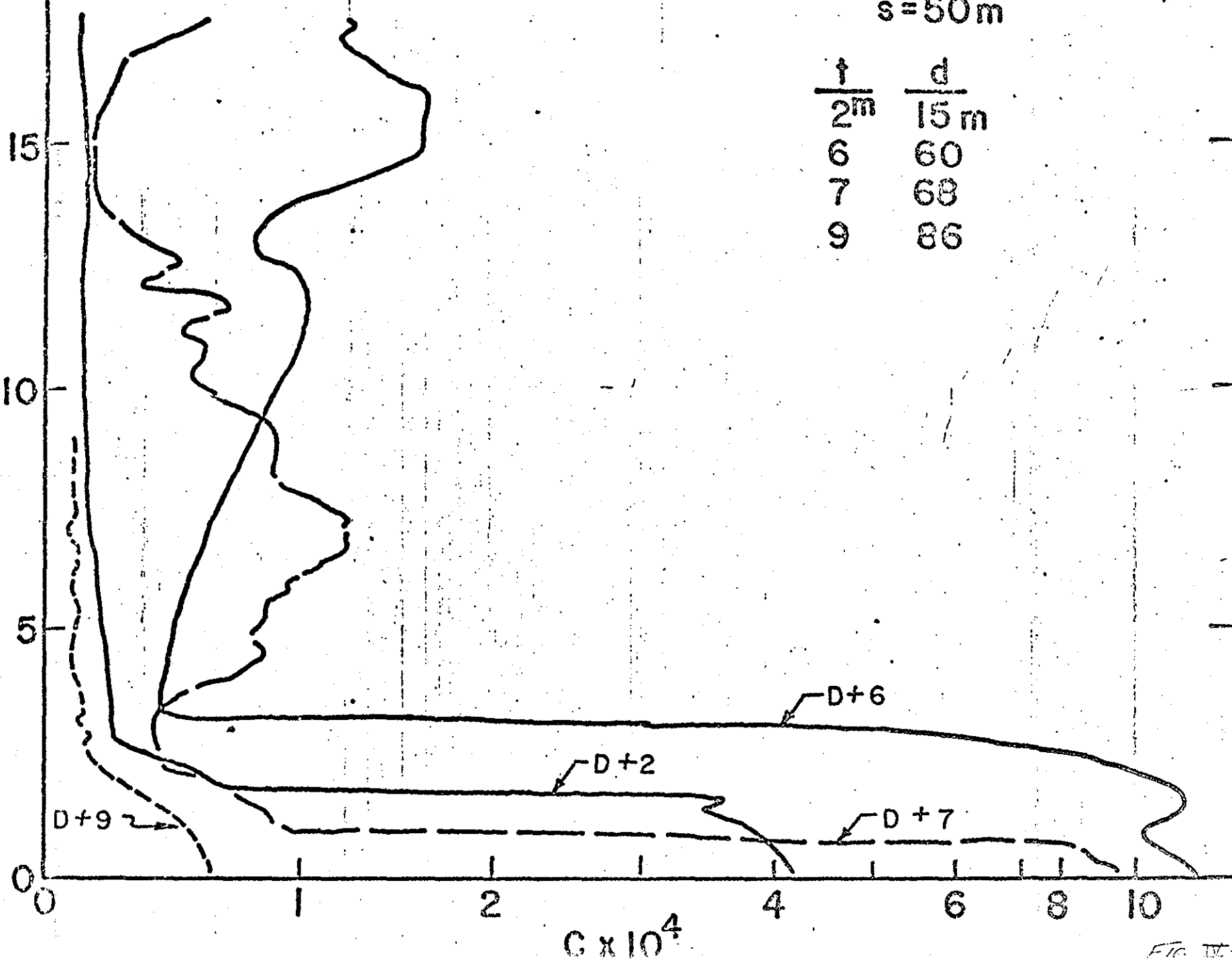
2C

251073

s=50m

Z, meter

$\frac{t}{2^m}$	$\frac{d}{15m}$
6	60
7	68
9	86



dropped. Profiles were taken at a rate of about one per minute; only representative examples are shown in the drawing. The table which appears in this figure gives the displacement of bottom water from the drop site at successive times after the end of spoil discharge as calculated from the current meter record. The arrival of the bottom turbid cloud at time D+2 min. is evident. Since the displacement of the bottom water in this 2 min. period is only 15 meters, it is evident that the bottom turbidity is spreading at a speed substantially in excess of the current speed. The surface turbid cloud is first detected at time D+6 min., when the water displacement is comparable to the distance between the drop site and the observing boat. It is concluded that this cloud has no lateral velocity in excess of the water velocity; thus it might be termed a drift cloud. Curves D+6 and D+7 show that the upstream end of the drift cloud is lower than the downstream end.

When a continuous record of turbidity near the bottom is made at a fixed station downstream from the drop site, a record like that in Fig. IV-3 is obtained. In this case the transmissometer was held 1 meter above the bottom 30 meters away from the scow. The bottom current at the time was 9 cm/sec. Zero time is the moment when the doors on the bottom of the scow were opened. The time required for the silt to fall through 18 meters of water, impact the bottom, and then spread laterally through 26 meters of water is 2.58 min. Highly turbid water continues to flow past the transmissometer for the next four and a half minutes, after which there is an irregular decrease down to the background level of turbidity.

Interpretation. Most of the material in the spoil consists of non-cohesive particles of silt and clay size, particles which by themselves

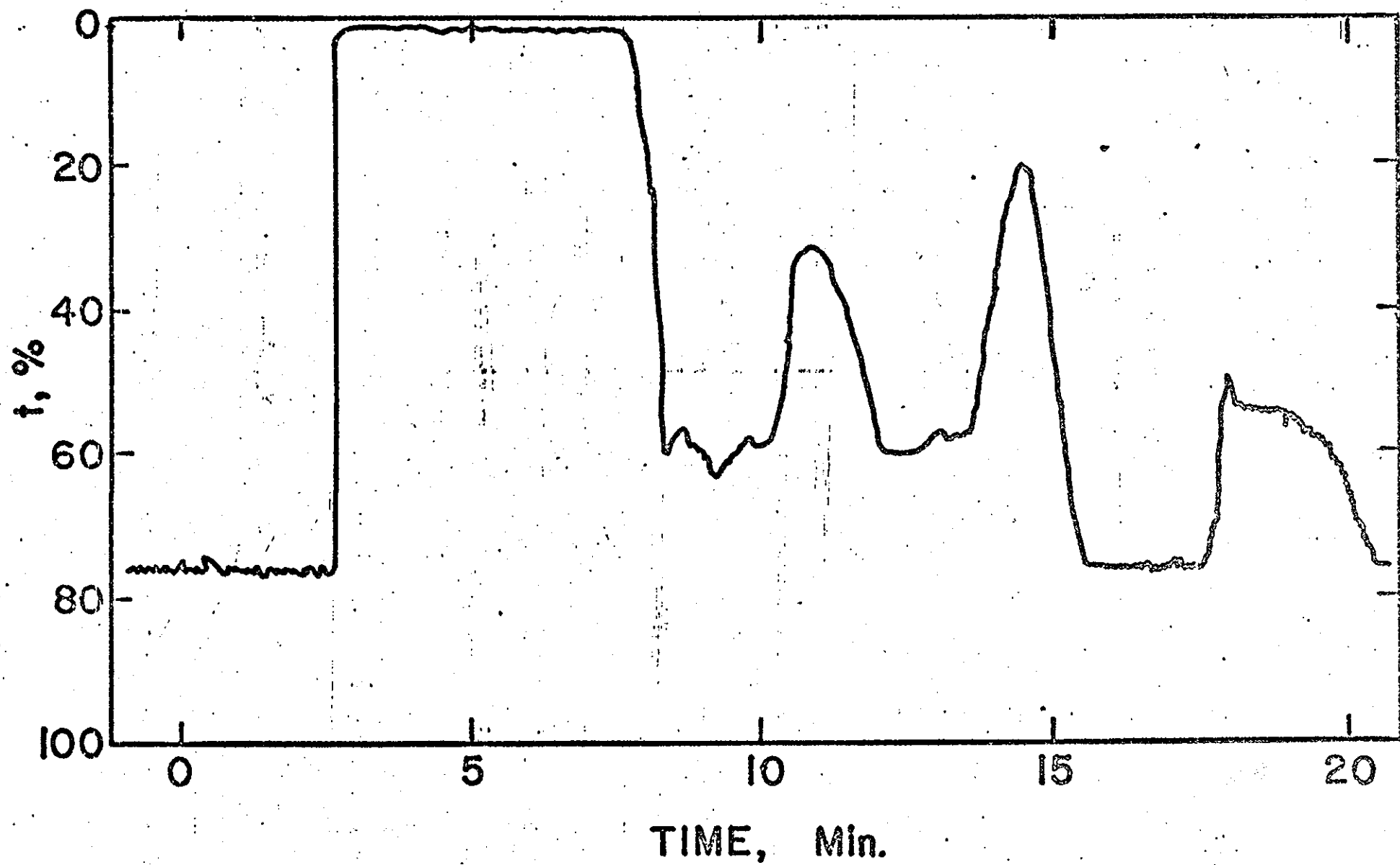


FIG. IV-3

would have a settling speed of no more than about 5 mm/sec (requiring over 65 min. to reach the bottom). The observations show that the spoil reaches the bottom very quickly, falling not as individual particles but as a density current. Upon impact with the bottom, the current spreads laterally to produce the observed bottom turbidity cloud. A small residue of fine particles does not go to the bottom with the density current and is left behind as the drifting upper cloud of turbidity. Material in this cloud sinks at approximately the single particle settling velocity. This qualitative model is observed to apply for all stages of the tidal stream at the New Haven dump site.

During the dumping operation the spoil appears to behave, to a first approximation, as a dense liquid. This is a consequence of its high water content (70 to 75%) and the extensive reworking it suffers during dredging. It is discharged from the bottom of the scow as a jet with an initial velocity of from 2 to 5 m/sec as a result of fall through the scow hoppers. (The velocity is calculated from the volume of spoil, the orifice dimensions, and the observed discharge time.) During fall to the bottom the jet will be accelerated by gravity, as long as it retains excess density, and retarded by drag at the head and entrainment of ambient water.

As the scow is dead in the water during discharge, the point of origin of the spoil jet is moving with the surface water velocity. Velocity shear will be encountered during transit to the bottom, but the downward jet velocity is sufficiently large compared to the speed of the tidal stream that only a small error is made in describing the spoil transport through the water in terms of coordinates fixed to a particle of bottom water directly under the scow at the time of discharge. Allowance for motion over the ground is then easily made in evaluating the total amount of dispersion.

The processes involved in the dispersion of wastes dumped at sea are summarized by Clark et al. (1971). Three stages of descent are recognized. In the first, convective descent, the waste cloud settles in consequence of its excess density and initial velocity. Due to entrainment of ambient fluid, the cloud density decreases while, with increasing depth, the density of the ambient water increases. Descent therefore ends at a critical depth and the second stage, collapse, occurs. This is followed by long term dispersion of the cloud. The important parameters are the Froude number based on cloud radius, b , and the parameter

$$E = b(dp/dz)/\Delta\rho$$

where dp/dz is the density gradient in the sea water and $\Delta\rho$ is the excess density of the cloud. In the case of dredge spoil dumped in well mixed coastal waters, as in Long Island Sound, dp/dz is small (the density difference between the top and bottom of the water column was $< 10^{-3} \text{ gm/cm}^3$ at the time of the observations reported here) and $\Delta\rho$ is large, 0.45 gm/cm^3 in the present case. This causes E to fall outside the range in which the analysis of Clark et al. is useful; the spoil is transported all the way to the bottom by convective descent. If the downflowing spoil can be described as a jet issuing from an orifice at the bottom of the scow, the amount of its spread due to entrainment can be estimated to a first approximation from turbulent boundary layer theory (Schlichting, 1960): The lateral spread of an axially symmetric, turbulent jet is equal to about 30% of the distance traveled from the orifice. At the New Haven dump site the increase in jet diameter during fall to the bottom would be 12 meters. This is consistent with the turbidity data and also with qualitative observations of the

descending spoil made with a 200 kHz echo sounder on a boat traversing the dump site; a good reflection is obtained from the top of the descending column of spoil so that an estimate of its size can be made.

The details of the interaction of the descending spoil with the bottom are unresolved as yet; presumably some resuspension of bottom sediment results from the impact. The turbidity observations clearly show, however, the generation of an outward spreading density current, or surge, of highly turbid water. The fall and spreading velocities of the density current can be conveniently studied with a travel time diagram in which the total distance traveled by the spoil downwards to the bottom and then outwards from the point of impact is plotted against time. The data from the available observations are not sufficient to yield highly accurate results, but clearly show the magnitudes of the physical processes involved. The applicable data are shown in Fig. IV-4; observations which place limits on the travel time (but do not specify actual values) are indicated by arrows. A downward arrow, for example, indicates that spoil is not observed and therefore had traveled a distance less than that indicated by the arrow head. The graph on the left is an enlarged version of the initial part of the curve on the right. Zero time is the time at which the spoil starts moving downwards from the scow. It must pass through 18 meters of water before hitting the bottom. The intercept of the travel time curve on a line corresponding to a distance of 18 meters gives, therefore, the fall time of the spoil from surface to bottom. The initial slope of the curve in the left-hand diagram is drawn as 2 m/sec, the value calculated for the occasion when the travel time to the bottom (the first data point) was measured directly. The observations show that the descent speed decreases

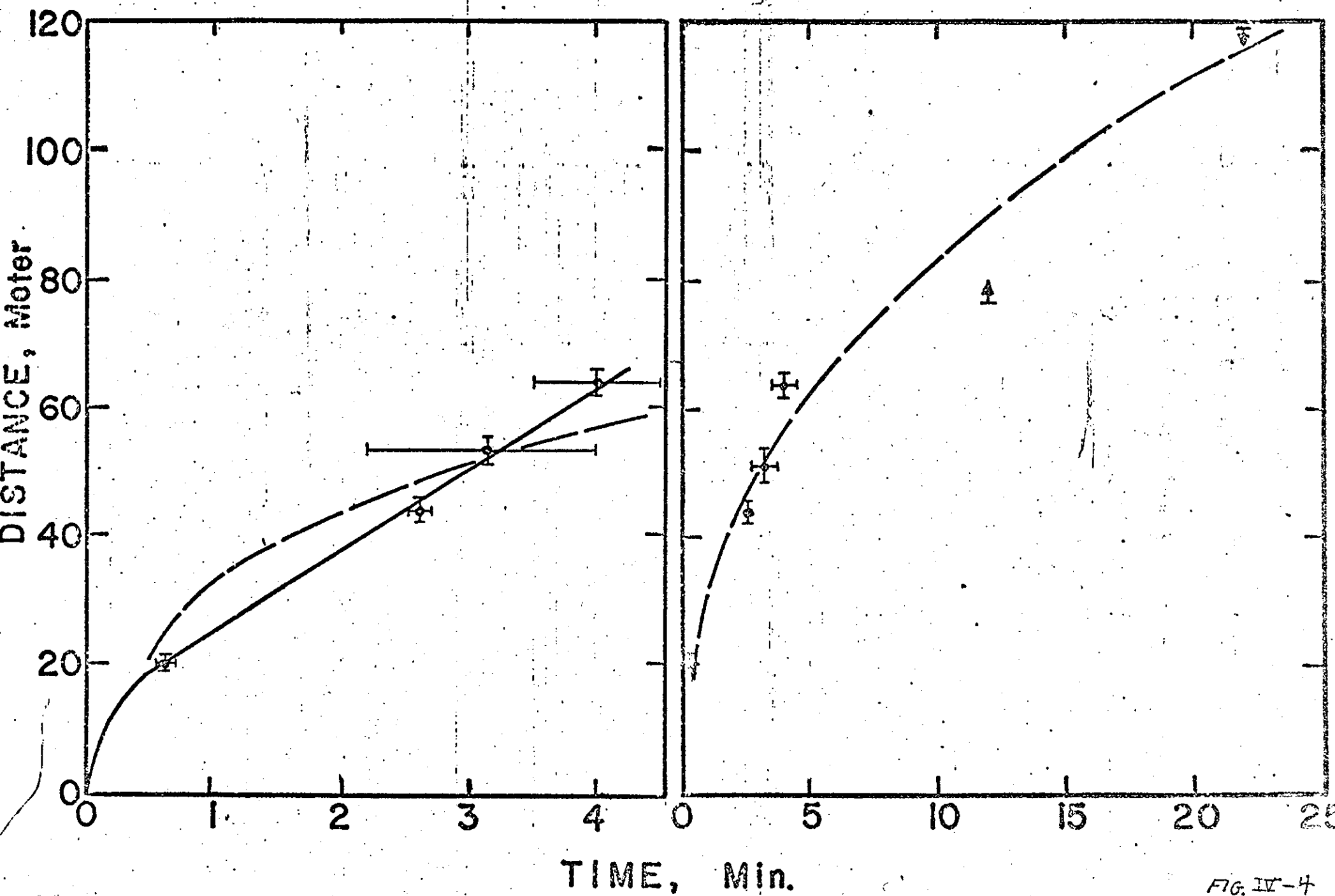


FIG. IV-4

with depth, i.e., that the velocity decrease due to entrainment and head drag exceeds the increase due to the excess density of the spoil jet. There is a discontinuous change in velocity upon bottom impact. The initial horizontal spreading speed of the bottom surge is about 12 m/min.; it subsequently decreases and the motion appears to be fully dissipated after about 15 minutes. Note that the motion described in Fig. IV-4 is measured with respect to the bottom water; the current speed (as indicated by the recording meter) must be added to find the speed over the ground. In most of the observations the speed of the water is small compared to the speed of the spoil. While the bottom turbid cloud is spreading, it is also thinning. All of the observations of the thickness of the bottom cloud are shown in Fig. IV-5.

Detailed analyses of the dynamics of density surges of suspended sediment are not now available, but one generalization confirmed by observations is that the Froude number

$$F = u / \left(\frac{\Delta \rho}{\rho} gh \right)$$

remains constant at about unity as the surge spreads over distance ℓ (Keulegan, 1957). Here U is head velocity of the surge, $\Delta \rho$ its excess density and h its thickness. This relation can be tested with the data given above: The excess density can be calculated from the observed concentration of solids and the thickness h has been measured. When $h = 200$ cm and $c = 10^{-3}$, $u = 7.2$ m/min., which is within a factor of 2 of the observed speed. This is about as close an agreement as could be expected from the data available. A consequence of the model is that, for axially symmetric spreading of a surge whose volume remains constant,

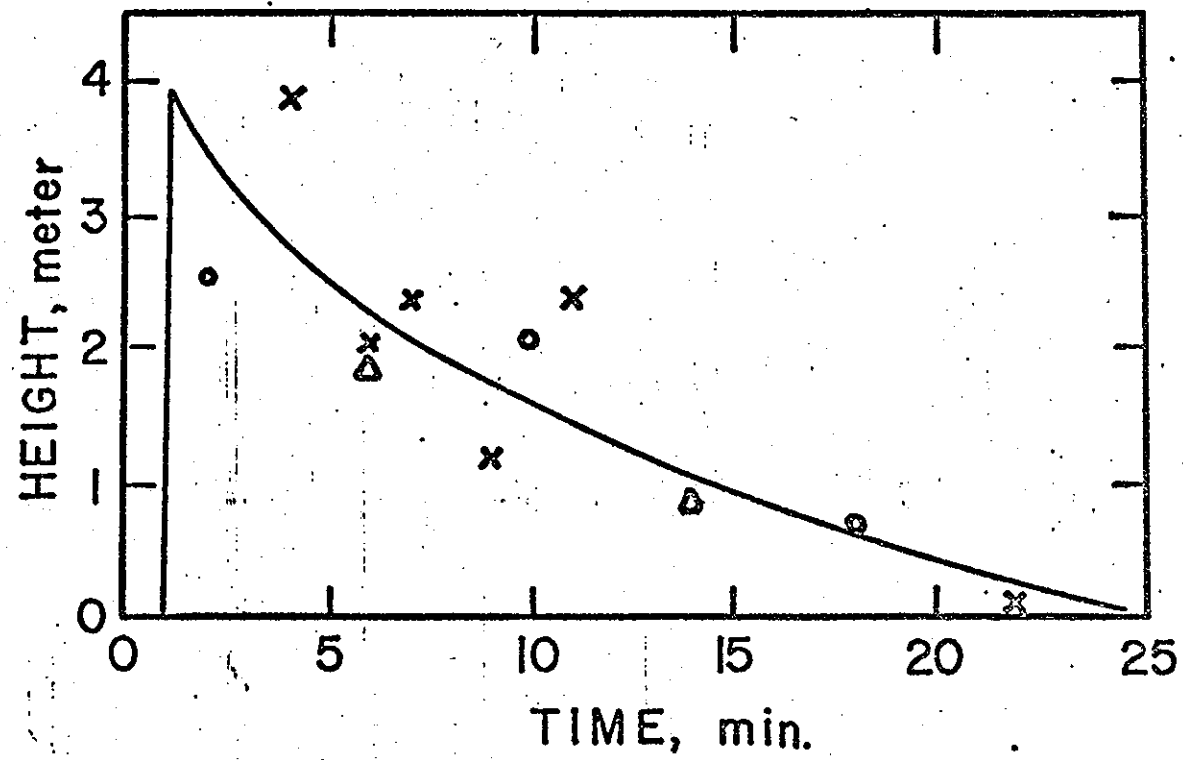


FIG. IV-5.

$$L \propto t^{1/2}$$

This relation is shown by the dashed curve in Fig. IV-4 and appears to hold to within the accuracy of the data. By about D+15 min. the bottom cloud has become so thin that the model may no longer apply. If this is so, the last arrow in Fig. IV-4 is no longer a significant constraint on the travel time curve.

If the speed at which the bottom turbid layer moves past a point, its height, and the concentration of silt it contains are known as a function of time, then the flux of suspended particles that it carries outwards from the dump site can be calculated. Data are at hand to make this calculation for a circular perimeter of 30 meter radius surrounding the drop site. The data in Figs. IV-3, 4, and 5 are used, and it is found that the greatest outward flux of solid particles is $0.90 \text{ m}^3/\text{min.}$ per unit length of perimeter. Integrating around the perimeter and over the time that the bottom cloud spreads outward sets an upper bound of 170 m^3 of solids transported outside the circle of 30 m radius for each scow discharge. This is approximately 18% of the material dropped from the scow.

A second way in which solids can be dispersed from the dump site is in the upper drifting cloud of turbid water. Because of the slow settling speed of this cloud, it will be carried a considerable distance by the tidal stream before its contained solids reach the bottom. The turbidity profiles define the approximate thickness (10 meters) and diameter (60 meters) of the drifting cloud. The total amount of solids it contains can be calculated from its measured turbidity. This is found to be 19 m^3 , or about 1% of the material dumped. Thus, the data show that at least 80% of the spoil in the scow reaches the bottom within a radius of 30 meters

around the drop site and 90% within a radius of 120 meters, and that only about 1% of the spoil is dispersed over a significantly greater distance. The above conclusions about the extent of spoil dispersion are confirmed by bathymetric surveys made at the New Haven dump site, as discussed in the next section of this report.

It is expected that the model of spoil dispersion developed for the New Haven dump site will be applicable to other localities so long as the spoil reaches the bottom by convective descent. The limits to which this mode of fall will apply can be estimated by the method described by Clark et al. (1971). In greater depths of water, the analysis of Koh (1971) may be applied. Increasing the sand content of the spoil, or decreasing the contained water, would increase the density contrast. Spreading during descent would not be much changed but the amount of fine material available to make the bottom density surge would be reduced. Spoil with a large clay content probably would not be liquified during bucket dredging and might not be discharged from the scow as a jet; free fall of individual blocks is more likely in this case.

V. SURVEYS OF THE DUMP SITE

At the completion of dumping operations, and during the following months, the dump site was examined to find the amount and disposition of spoil present and evidence of its movement.

Bathymetric Surveys. The dump site surveys were made using a Raytheon precision survey fathometer. Tide height corrections were made by running the survey lines through a buoyed fixed point, the South Control Site, having a nearly flat bottom at a depth previously determined by the Corps

of Engineers in the original site surveys. Two of the surveys were detailed and utilized a precision electronic navigations system ("Cubic Autotape" microwave system with transponders at Stratford Pt. light and the New Haven abandoned light tower). The others were run on a single east-west track through the dump buoy location with the aid of auxiliary buoys "J", 844 yards east of the dump buoy, and "K", 1420 yards west of the dump buoy. All buoy positions are subject to some variation due to the scope in their mooring. Surveys were made on the following dates in 1974:

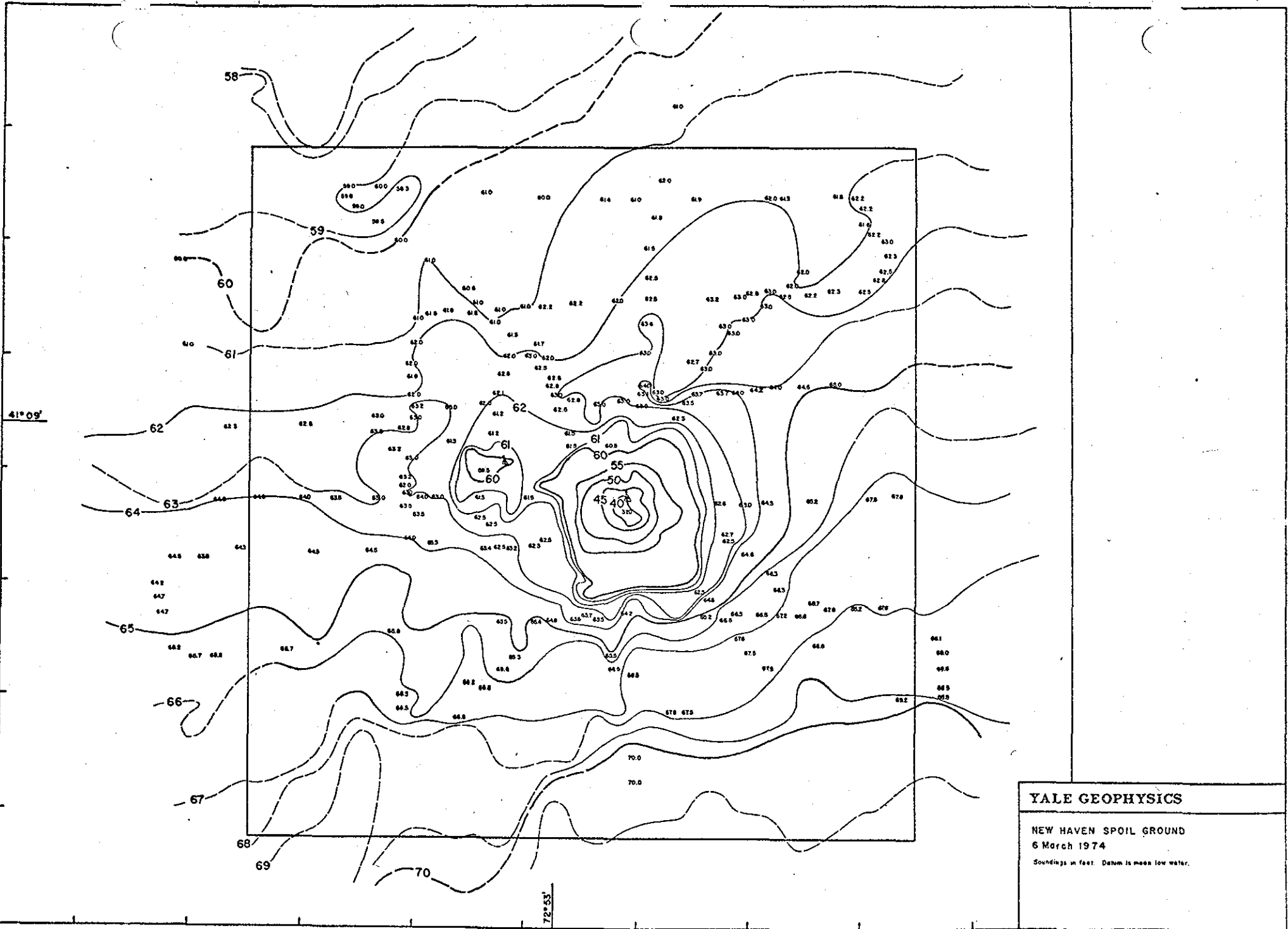
24 January	11 May
6 March*	27 May
28 March	26 July
18 April	19 November*

(Those marked "*" are detailed surveys based on the electronic navigation system.)

At the time of the survey on 6 March the dumping operations were almost completed; the configuration of the spoil pile on this day is, therefore, very nearly its final form and subsequent changes would be due to erosion or compaction of the spoil. The measured topography of the dump site on 6 March is shown in Fig. V-1. The high cone of material at the dump buoy is immediately evident. The smaller cone to the west is present because the position of the dump buoy was shifted on 31 October 1973 (while the buoy light was being repaired by the Coast Guard). The buoy positions are

To 31 Oct.	R_1 (to Stratford Pt. Lt. Ho.) 18359 m,	R_2 (to Old Tower) 11205 m
After 31 Oct.	$R_1 = 18702$ m	$R_2 = 11363$ m

A comparison of the bathymetric survey made on 6 March 1974 with surveys made before dumping operations began should permit determination



YALE GEOPHYSICS

NEW HAVEN SPOIL GROUND
6 March 1974

Soundings in feet. Datum is mean low water.

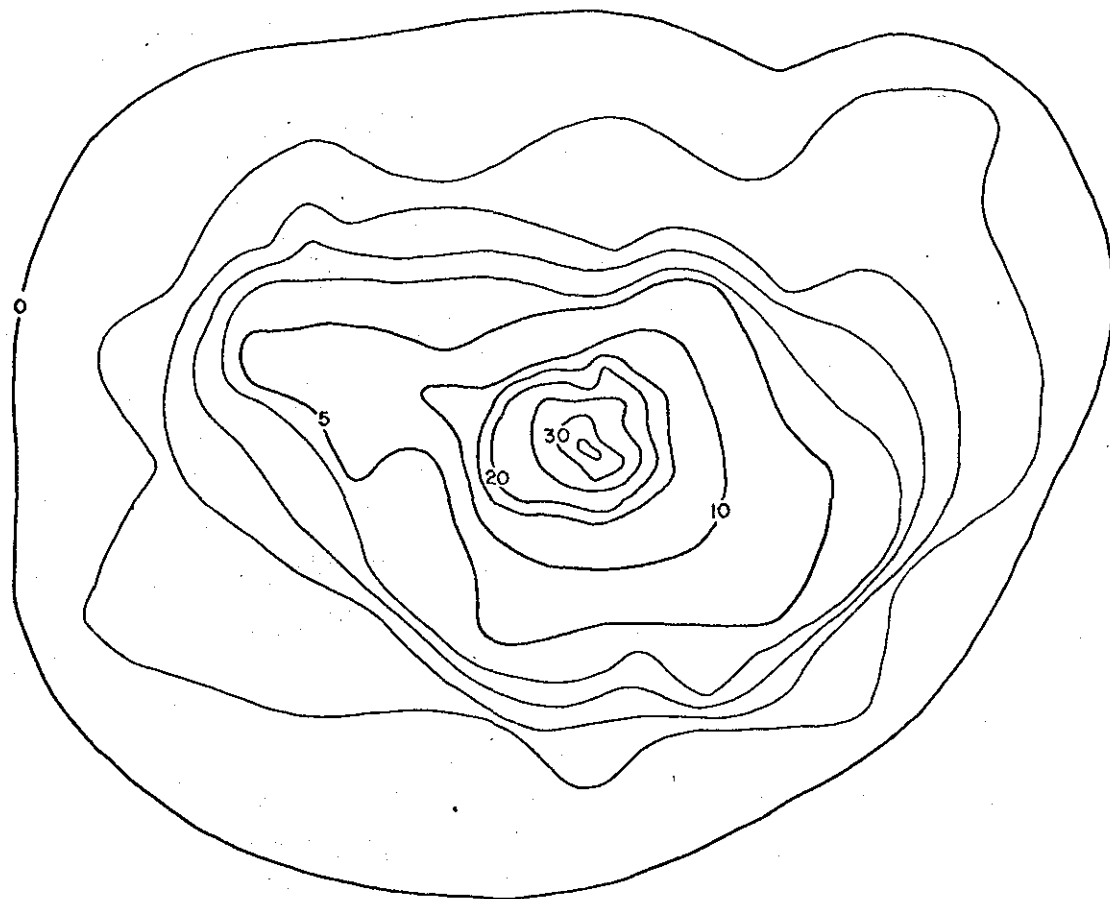
Fig. N-1

of the volume of spoil present on the site. In order to make the comparison it is necessary to allow for downward deflection of the bottom under the weight of the spoil pile. A good estimate of the magnitude of this deflection can be made from the measured hardness of the bottom at the dump site (Bokuniewicz, Gordon and Rhoads, 1975). "Hardness" is the normal stress required to produce a unit downward deflection of the sediment-water interface under drained conditions. It is insensitive to the rate of loading. Hence, the bottom hardness measured with a penetrometer (Gordon, 1972) should be a good representation of bottom deflection under the long-term load applied by the deposited spoil. The average measured bottom hardness at the disposal site is 20 mbar/cm. When silt-clay spoil containing about 70% water is placed on bottom sediment of this hardness, the downward deflection of the bottom is very nearly equal to 20% of the height of the spoil above the original, undeflected, sediment-water interface.

The thickness of the spoil deposited on the dump site up to 6 March 1974 was calculated from the measured changes in bottom topography with the above described correction for bottom deflection applied. Thickness contours for the dump site are shown in Fig. V-2; also shown is an east-west cross section of the spoil deposit (with a 50 to 1 vertical exaggeration). Contours are drawn at 1 foot intervals for 0 to 5 ft. and at 5 ft. intervals thereafter. The "0 ft." contour is the outer bound of the area where a difference in water depth greater than 0.2 ft. before and after dumping could be detected. Small amounts of spoil may be present outside the area bounded by this contour.

The measured volume of spoil in the pile shown in Fig. V-2 is $1.5807 \times 10^6 \text{ yd}^3$. On March 6, the survey date, the total amount of spoil which had been dumped since the start of dredging was $1.479714 \times 10^6 \text{ yd}^3$. Several

100 Yd

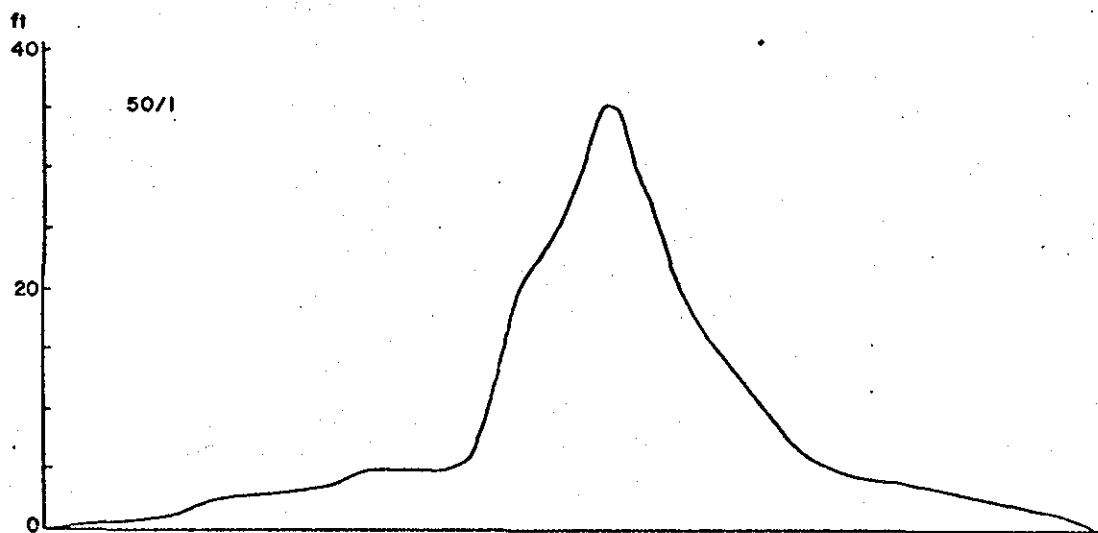


ft
40

50/1

20

0



factors must be considered if these two figures are to be compared to see if all of the spoil dumped can be accounted for on the site. First, the amount dumped is based on dredge operator's estimates of the amount of spoil placed in each scow. Three different dredges, each with several crews, were at work during the project. It is difficult to evaluate the accuracy of their estimates; a 10% error seems quite possible and would easily account for the difference between the figures given above. Second, it is to be expected that there will be some difference, probably an increase, between the water content of the spoil in the scows and that of the freshly deposited spoil on the bottom of the Sound. If the increase were from 72.5%, as measured in the scows loaded with silt-clay spoil, to 74.4%, the volumes of spoil dumped and measured on the bottom would be in agreement. Third, the water content of the spoil is determined from a one meter long core taken from a filled scow; the water content at the bottom of the scow may be somewhat less. The water content of the spoil pile is expected to be non-uniform: Spoil was dumped over a period of six months. The older spoil will be compacted by the newer spoil on top. Only the top could be sampled by the gravity and box corers used. For all these reasons precise determination of the actual volume of solids dumped and the volume of solids in the spoil pile could not be made. However, the results show that the loss of the spoil from the designated dump site during dumping, if any, is a very small fraction of the amount of material discharged.

According to the analysis presented in Section IV alone, spoil dumped at the New Haven site should be placed on the bottom within a circle of about 200 yd. radius centered on the scow position. The scope on the dump buoy mooring is about 3 times the water depth, or 180 ft. The buoy is, therefore,

expected to swing through a radius of about 50 yd. Scows may have been as much as 200 yd. away from the buoy when dumped. Most of the spoil should, therefore, be within about a 450 yd. radius. Examination of Fig. V-2 shows that, when allowance is made for the fact that the dump buoy was moved on 31 October, this is actually the case.

Surveys made after 6 March 1974 show that there have been changes in the configuration of the spoil pile after dumping was completed. The measured height of the top of the pile at successive times after completion of dumping is shown in Fig. V-3. In this diagram the first and last points, based on detailed surveys, are more reliable than the intermediate ones, which are based on positions determined from buoys. (The error bars in Fig. V-3 refer to the uncertainty in depth measurement only. Examination of Fig. V-1 shows that the swing of the dump buoy on its scope will change the profile measured somewhat.) The height of the spoil pile has been decreasing, more rapidly at first and then more slowly. The resultant change in the configuration of the pile in E-W sections J-D-K (see Fig. II-1) is shown in Fig. V-4. The decrease is greatest in the center and is approximately proportional to its height.

Both erosion and consolidation may contribute to the observed shrinkage of the spoil deposit. The following evidence indicates that consolidation is the principal cause of the changes observed:

- i. The decreasing rate of change of height of the pile (Fig. V-3) is expected for the self-consolidation by dewatering of soil under its own weight because the permeability of the spoil decreases as it settles. An alternative hypothesis is that the resistance of the pile surface to erosion increases, rapidly at first and then more slowly. This is unlikely for

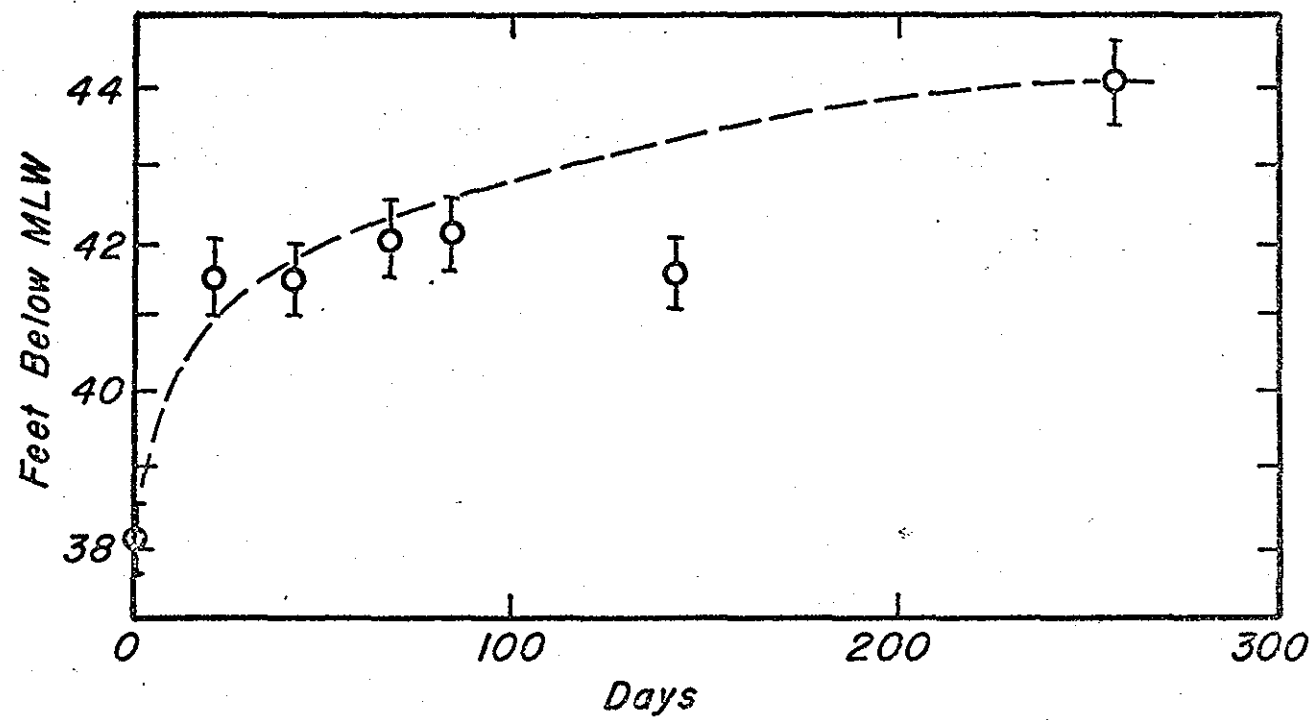


FIG. IV-3

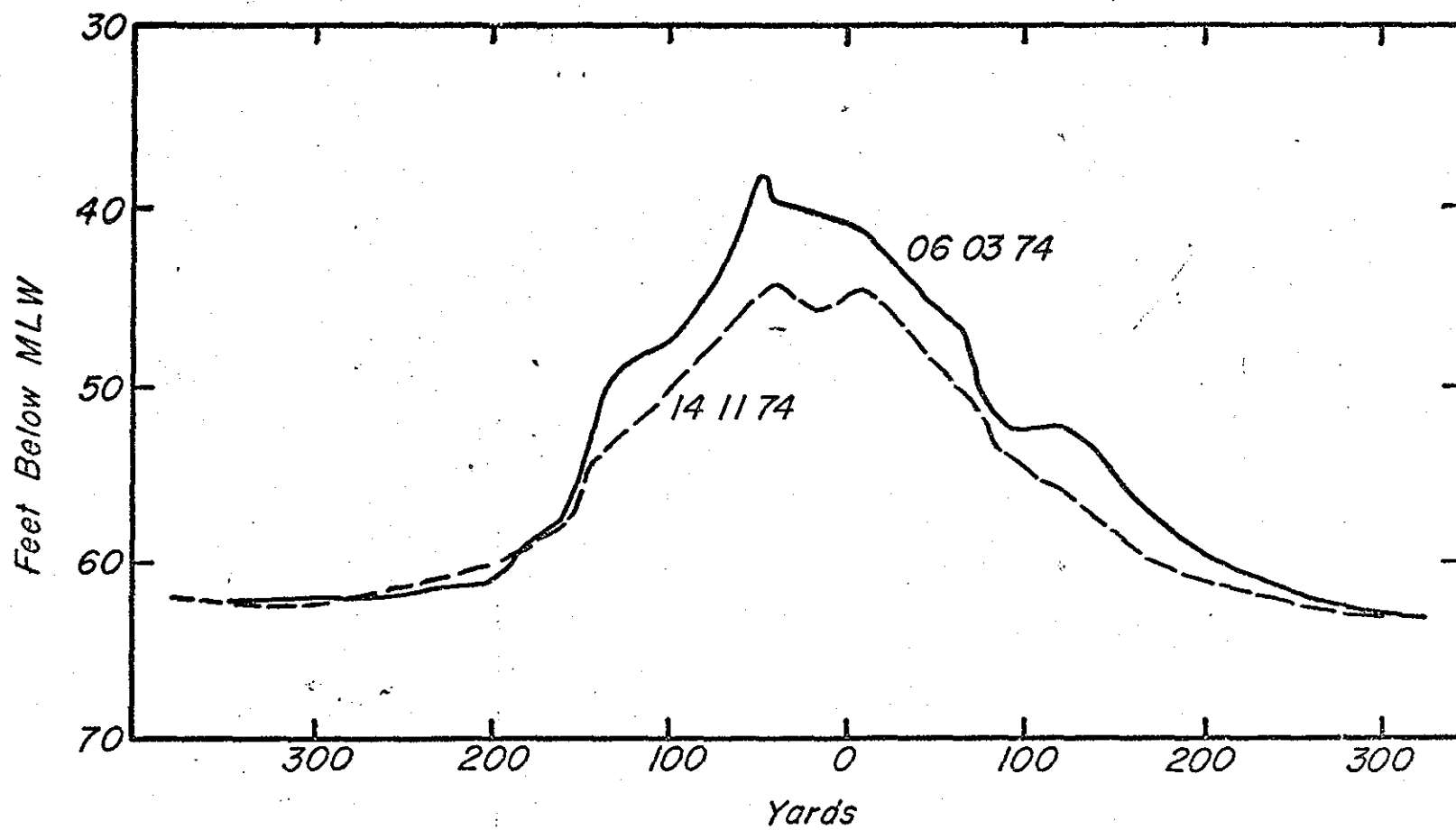


FIG. IV-4

two reasons: First, the surface of much of the pile has been covered with sand at all times since completion of dumping and was free of animals until at least June 1974. Second, the measured increase in critical erosion velocity for the pile surface (Rhoads, 1974, personal communication) was greatest in late summer.

ii. In self consolidation shrinkage should be proportional to thickness, as is observed.

iii. The measured water content of box cores taken from the pile in the Fall of 1974 is 50% (Aller, 1974, personal communication); in late Spring of 1974 it was greater than 60% (Ullman, 1974, personal communication). These data, and the observed change in spoil thickness, imply substantially higher water content in March 1974.

iv. There is no evidence of any extensive transport of material away from the dump site (see below).

A consequence of consolidation of the spoil by loss in interstitial water is that there would be a net outward flux of fluid through the sediment-water interface of the spoil pile. To estimate the magnitude of this flux, suppose that the settling occurs uniformly throughout a column of spoil under a unit surface area. Let h = the spoil thickness, c the volume fraction of interstitial water and v the velocity of outward flow of interstitial water. Then

$$v = c(dh/dt)$$

The greatest dh/dt occurs at the top of the spoil pile and from Fig. V-3 is $0.22 \text{ ft/day} = 6.6 \text{ cm/day} = 7.6 \times 10^{-5} \text{ cm/sec}$. Since $c = 0.7$, the greatest v is $\sim 5 \times 10^{-5} \text{ cm/sec}$. This outward advection will oppose any inward diffusion processes which may be active. Its magnitude will decrease with

time and with distance from the center (thickest) part of the pile.

Current Meter Measurements. The top of the spoil pile reaches 23 ft. upwards into the water column at the dump site. Current meter measurements were made to detect any change in the pattern of water flow over the site which might result. In September 1974 one meter was placed at buoy "J", 844 yards east of the dump buoy, and a second was placed on the top of the spoil pile. These meters were recording simultaneously; both were set 2 m above the bottom. In comparing the results obtained at the two stations, allowance must be made for the large fluctuating component of velocity which is observed at all stations in central Long Island Sound. To eliminate the effect of these fluctuations it is necessary to compare records of at least 10-days duration. One way of doing this is to examine the velocity histograms calculated from the records. These are shown in Fig. V-5 where the number of times current velocities fall within successive velocity intervals, n/N , is plotted against the magnitude of the velocity. The greatest expected tidal velocity at this station is ~ 30 cm/sec; the occasional occurrence of much higher current speeds is evident in the histogram for station "J". Figure V-5 shows that the current speeds over the top of the spoil pile (curve D) is increased by a factor of about 30% over that on the surrounding sea floor. The top of the range of tidal speeds is about 40 cm/sec and the range of higher velocity fluctuations is correspondingly increased.

While the increased current observed at the dump site may be due to a local alteration in the flow regime caused by the presence of the spoil pile, some or all of the increase may be due to the fact that the meter on

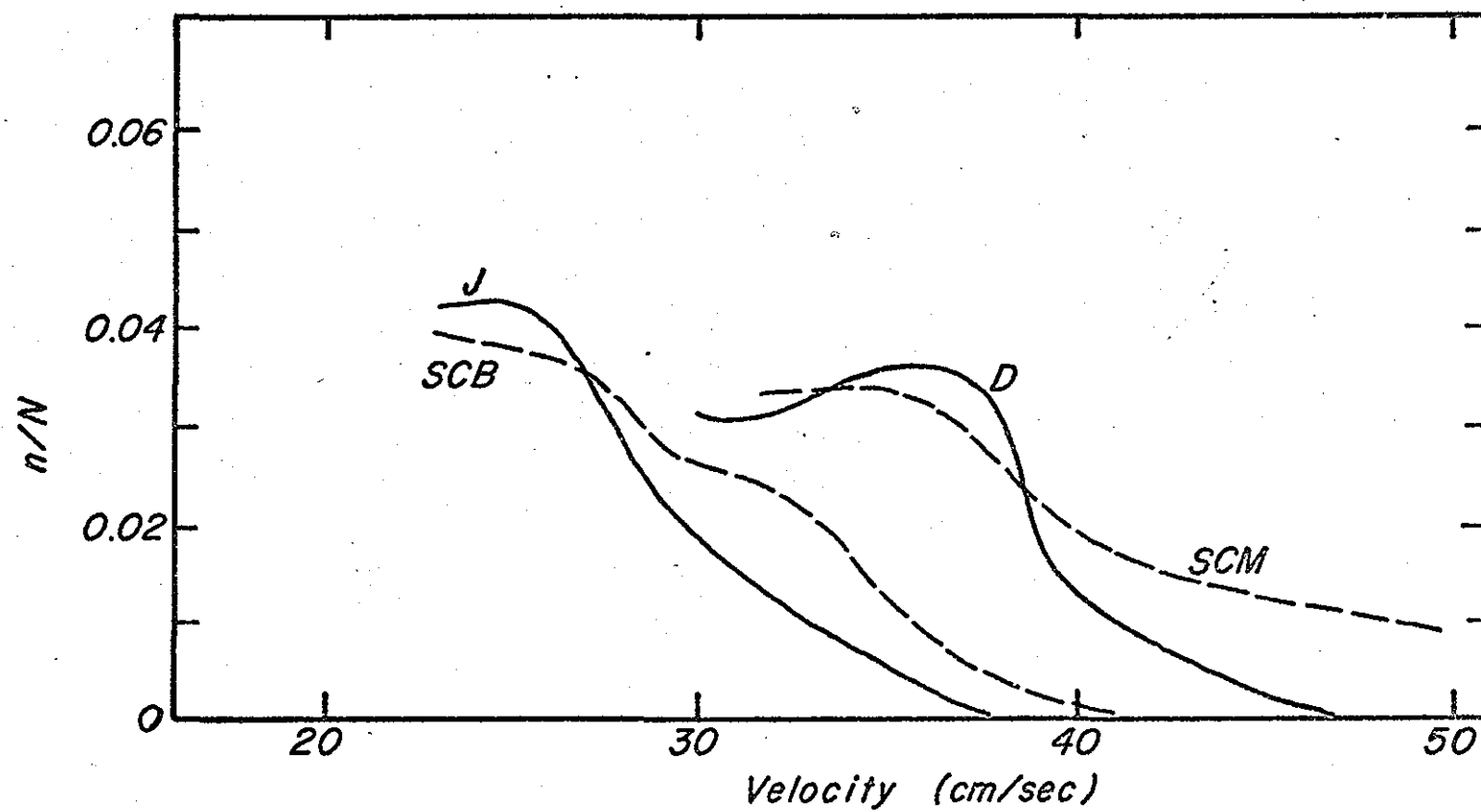
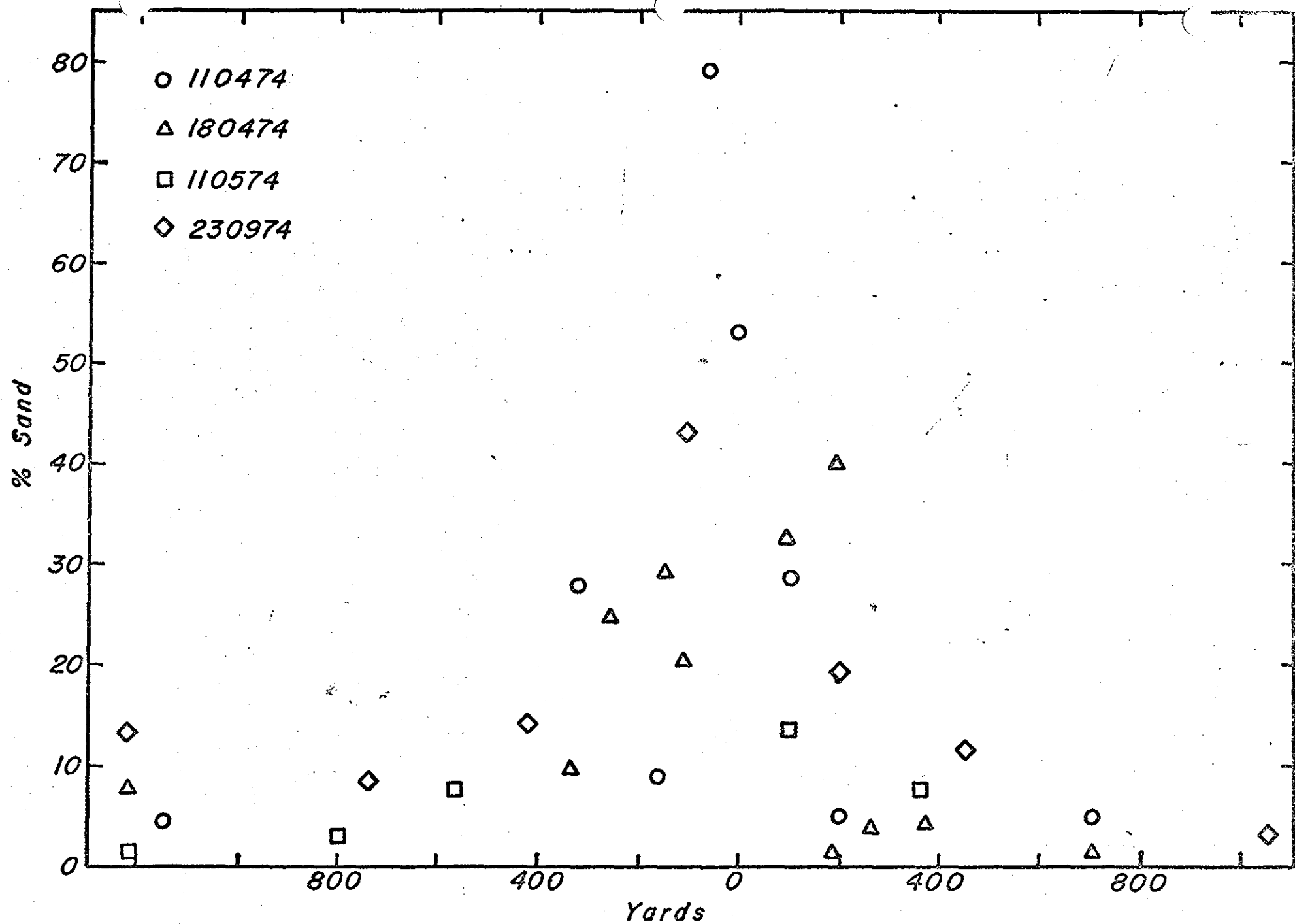


FIG. V-5

the top of the pile is sampling higher in the water column, where velocities are naturally greater. This possibility may be tested by comparing the results obtained at the dump site with those from a vertical array of three current meters operated at the South Control site in December 1973. The bottom and middle meters in this array were placed at the same relative depths in the water column as the meters at the dump site and at station "J". The histograms calculated from these records are shown in Fig. V-5, curve SCB is for the bottom meter and curve SCM is for the middle meter. The increase in current speed at mid depth at the South Control site is comparable to that observed at the top of the spoil pile. (Actually, the enhancement of the highest speeds is somewhat greater and of the intermediate speeds, somewhat less, at the South Control site.) Hence, it appears that the spoil pile, despite its size and considerable height, has little or no measurable effect on the speed of water movement over the dump site.

Bottom Samples and Reflectivity Measurements. The uppermost material on the spoil pile is sandy while the surrounding sea floor is nearly sand-free mud. If erosion of sand from the pile with subsequent deposition outside of the dump site area occurs, it may be possible to detect a superficial deposit of sand on the muddy bottom. In order to detect this, short cores were collected along track J-D-K at increasing time intervals after completion of dumping. Each core was divided into 1-cm thick layers beginning at the sediment-water interface and each layer was sieved in order to determine its sand/mud ratio, i.e., the relative amounts of material retained on, and passed by, a 64 μ screen. The results obtained for the uppermost layer in each core are shown in Fig. V-6. The cores were collected on four different dates; the horizontal scale of distance is centered on the dump



buoy. The high sand content of the material on the top of the spoil is evident. However, there is a very large scatter of individual values from each sampling date, evidence of the "patchy" character of the spoil deposit. A further source of scatter in the data is the variation in buoy position (due to mooring scope) discussed above. There does not appear to be any systematic shift in the sand distribution distinguishable from the scatter in the data. For this method of detecting dispersion of sand to be effective it is evident that a much greater number of samples would have to be collected (to get proper averaging over the patchy bottom) and use of a more precise system of navigation would be desirable.

Another attempt at detecting spreading of sand was made by measuring the variation in the relative acoustic reflectivity of the bottom for 200 kHz pulses along a track J-D-K. The reflectivity is sensitive to small changes in sand content and good averaging is obtained since a continuous record is made along the track. However, each track must be calibrated (to allow for adjustment of instrument gain and water depth) at one or more places of known sand content. The results obtained at the dump site are limited in usefulness because of difficulties encountered in intercalibrating the tracks run on different dates and, as above, by the navigational inaccuracies resulting from the necessary reliance on local buoy positions. All tracks show the general variations of sand content over the spoil pile but do not reliably detect any dispersion.

Turbidity at the Dump Site. During the preliminary (pre-dumping) phase of this study regular turbidity measurements were made at and around the dump site for over a year. The turbidity profile from surface to bottom

was measured and used to calculate the total amount of suspended sediment in the water column at the place and time of measurement (methods and results are discussed in earlier reports). Similar measurements were made from time to time after completion of dumping operations; no significant deviation from the turbidity conditions obtaining before dumping were observed.

VI. CONCLUSIONS

The observations at the New Haven dump site were made while commercial dredging contractors were carrying on their work according to the generally accepted procedures of the industry. A controlled dredging-dumping experiment was not done. Thus, the objective was to extract as much information as possible from the measurements that could be made with the resource available. Before dumping began little information was available as to what variables would be important or how great their range would be. For these reasons the data are not as complete as they would be if this were a fully controlled dredge-dump study planned and funded so as to obtain maximum scientific value. Nevertheless, a great deal has been learned about the physics of the processes active in dredging and ocean disposal of spoil.

Turbidity Due to Dredging. The bucket dredge operating in the tidal stream in New Haven Harbor is found to act as a continuous point source of turbidity. Measurement of the flow of turbid water away from the dredge shows that about 2.5% of silt lifted from the bottom is lost into the surrounding water. In New Haven Harbor the resultant siltation is small compared to that due to winter storms except in an area about 500 x 200 meters (long axis along the tidal stream direction) extending downstream from the dredge.

Dispersion of Spoil During Dumping. Turbidity measurements show that 99% of non-cohesive spoil of high silt content discharged from a scow in the presence of a tidal stream is transported to the bottom as a high-speed density current. Lateral spread of this current is about 30% of the water depth. Impact with the bottom produces an outward-spreading surge whose speed and thickness vary such that the Froude number of the flow remains constant. When 2000 cu. yd. of spoil is discharged in water 20 m deep, the surge carries less than 18% of the spoil outside a circle of 30 m radius, and essentially none beyond 120 m. The residual turbidity in the water column, which drifts with the tidal stream, contains less than 1% of the material discharged; this settles at the fall speed of the individual particles.

A bathymetric survey made near completion of dumping operations shows that all of the material dumped is accounted for in the spoil pile to within the limits of the accuracy of measurement. The observed spread of spoil about the designated dump point is accounted for by the cumulative effect of the swing of the dump buoy on the scope of its mooring, the measured spread of spoil during descent and bottom impact, and the positioning of the scow relative to the dump buoy. The results show that good precision can be attained in the placement of spoil at a designated place on the bottom, and that very little material escapes during placement, even when dumping is carried on in the presence of a strong tidal stream and in sea states ranging up to the limit at which dredge and scows can be safely operated.

Dispersion of Spoil After Dumping. Repeated bathymetric surveys after completion of dumping show shrinkage of the spoil pile. This is shown to

be due to compaction and consolidation of the spoil rather than erosion of the spoil. The compaction process results in the expulsion of interstitial water. Transport of the spoil outside of the designated dump area was not detected by either analysis of core samples or acoustic reflectivity measurements.

VII. RECOMMENDATIONS

Dumping Procedure. Alternatives to point dumping should be considered.

Point dumping builds the spoil pile to a maximum height. Advantages of this are deeper burial of the first-dumped spoil and its greater compaction and isolation from the water above. This may help suppress release of pollutants which are actually buried with the spoil. Further, a conical shape tends to minimize the surface to volume ratio of the spoil pile.

Largely negating the above advantages is the fact that the great bulk of spoil is not in the central core but in the surrounding flanks, where the thickness is relatively small. (This may be easily seen by calculating the volume of successive horizontal slices of the pile shown in Fig. V-2. Two thirds of the total volume of spoil is between the 0 and 1 ft contours.) Thus most of the spoil is not deeply buried and is exposed to direct contact with the sea water and benthic animal life. Furthermore, the central peak of the pile is exposed to the greater current speeds that occur higher in the water column. It is also more exposed to disturbance by storm-generated waves. (This latter effect has not yet been quantitatively evaluated at the New Haven dump site; observations of storm reworking of the bottom at the Northwest Control site suggest it will be a significant effect.)

It is, therefore, recommended that "point" dumping be replaced by "controlled area" dumping, unless the water at the dump site is very deep.

The objective in controlled area dumping would be to space out the actual drop locations so as to construct as nearly as possible a flat-topped spoil pile with side angles as steep as possible (consistent with slope stability). This would result in deeper burial of a larger fraction of the spoil, would better utilize the spatial capacity of the spoil ground, and leave the spoil less susceptible to disturbance by currents and by storms.

Site Capacity. The studies at the New Haven dump site define the consequences of dumping 1.5 M cu. yd. of spoil. Determination of the capacity of the site depends on relating these consequences to the amount of spoil dumped and the rate at which it is deposited. It also depends on the establishment of some criteria as to what consequences are acceptable and what are not. An approach to the first part of this problem could be started now by taking advantage not only of the data collected at the dump site but also the extensive background studies which have been completed. The approach would have to be along the lines of quantitative modeling of the processes which have been identified as active at the dump site and its environs. Presumably, this would start with the simpler, better defined processes of bed-load and suspended load transport of sediment by the tidal stream and would proceed to the more complex issue such as the effects of turbulence, storms, and benthic animals on the transport. It should also be possible to model the principal chemical processes that have been identified and the biological succession of animals living on the spoil.

It is recommended that a quantitative evaluation of the capacity of the New Haven Dump Site be initiated along the lines outlined above.

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<u>Title</u>	<u>Author(s)</u>	<u>Date</u>
A Report to the U.S. Army Corps of Engineers and the United Illuminating Company on the Environmental Consequences of Dredge Spoil Disposal in Central Long Island Sound:		
I. The New Haven Spoil Ground and New Haven Harbor	R. B. Gordon D. C. Rhoads Karl K. Turekian	October, 1972
II. Benthic Biology of the New Haven Harbor Channel and Northwest Control Site	D. C. Rhoads	February, 1973
III. Benthic Biology of the South Control Site, 1972	D. C. Rhoads	April, 1973
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V. Benthic Biology of the Milford, Branford, and Guilford Dump Grounds	D. C. Rhoads	January, 1973
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<u>Title</u>	<u>Author(s)</u>	<u>Date</u>
VIII. Changes in spatial and temporal abundance patterns of benthic mollusco sampled from New Haven Harbor, Dump Site, S. Control, N.W. Control Sites; 1972-73 (pre-dump baseline)	D. C. Rhoads	March, 1974
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